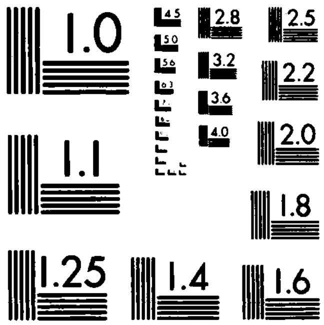
AD-A155 240 MEDIUM RANGE ATMOSPHERIC FORECAST SYSTEM: EVALUATION REPORT(U) SYSTEMS AND APPLIED SCIENCES CORP MONTEREY CA P A PETIT ET AL. FEB 85 NEPRF-CR-85-04 N00228-83-C-3101 1/1

UNCLASSIFIED F/G 4/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NAVENVPREDRSCHFAC
CONTRACTOR REPORT
CR 85-04

2

NAVENVPREDRSCHFAC CR 85-04

AD-A155 240

MEDIUM RANGE ATMOSPHERIC FORECAST SYSTEM: EVALUATION REPORT

Pierre A. Petit, Harry D. Hamilton, Russell L. Elsberry
Systems and Applied Sciences Corporation
Monterey, CA 93940

Contract No. N00228-83-C-3101

FEBRUARY 1985

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

Prepared For:

NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY
MONTEREY, CALIFORNIA 93943-5106

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

AD A 155 240

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S): CR 85-04
6a. NAME OF PERFORMING ORGANIZATION: Systems and Applied Sciences Corporation; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: Naval Environmental Prediction Research Facility
6c. ADDRESS (City, State, and ZIP Code): 570 Casanova Avenue, Monterey, CA 93940	7b. ADDRESS (City, State, and ZIP Code): Monterey, CA 93943-5106
8a. NAME OF FUNDING / SPONSORING ORGANIZATION: Naval Air Systems Command; 8b. OFFICE SYMBOL (If applicable): (AIR-330)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: N00228-83-C-3101
8c. ADDRESS (City, State, and ZIP Code): Department of the Navy, Washington, DC 20361	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 63207N; PROJECT NO. 7W0513; TASK NO.; WORK UNIT ACCESSION NO. DN293603

11. TITLE (Include Security Classification)
Medium Range Atmospheric Forecast System: Evaluation Report

12. PERSONAL AUTHOR(S)
Petit, Pierre A.; Hamilton, Harry D.; Elsberry, Russell L.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 8/83 TO 2/85	1985, February	86

16. SUPPLEMENTARY NOTATION
See also contractor report NAVENVPREDRSCHFAC CR 85-03, "Medium Range Atmospheric Forecast System: Evaluation Plan" dated February 1985

17. COSATI CODES FIELD	GROUP	SUB-GROUP
04	02	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Numerical weather prediction,
Medium range forecast,
Forecast verification

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The results of a comprehensive evaluation of the accuracy and utility -- with respect to operational Navy applications -- of a medium range (5-7 day) atmospheric forecast system are presented. Several nonstandard, but operationally relevant, objective measures of forecast model skill are employed, along with more traditional measures. Summary conclusions and recommendations for future evaluations are provided.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: Payne, Steven W. (contract monitor)	22b. TELEPHONE (Include Area Code): (408) 646-2326; 22c. OFFICE SYMBOL: NEPRF WU 6.3-20

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

TABLE OF CONTENTS PAGE

A-1

TABLE OF CONTENTS

SECTION 1. EVALUATION OVERVIEW

1.1 Background. The Navy has little experience in evaluating the usefulness of numerical environmental predictions prepared for periods greater than 3 days. Recognizing this, the Naval Environmental Prediction Research Facility (NEPRF) embarked in 1983 on a four-part project to develop a procedure which could establish the relevant accuracy and operational utility of a medium-range (5 to 10 day) atmospheric forecast system.

In the first part of this Medium-Range Forecast Evaluation (MRFE) project, a review was prepared which addressed the present accuracy and operational use of medium-range numerical forecasts for, in particular, Navy applications. This review (Elsberry, Hamilton and Petit, 1984) describes present levels of medium-range forecast skill and sets forth acceptable medium-range levels of accuracy for various operationally relevant weather parameters.

In the second part of this MRFE project, a detailed plan for evaluating the likely operational benefits of a medium-range forecast system was prepared. The Medium-Range Atmospheric Forecast System Evaluation Plan (Petit, Hamilton and Elsberry, 1984) calls for two months of forecast data collection and subsequent verification and assessment of skill and utility of both objective and subjective forecasts.

The third part of this MRFE project consisted of collecting and saving selected output from the Navy Operational Global Atmospheric Prediction Systm (NOGAPS) and various forecasts prepared therefrom in accordance with the Evaluation Plan. This collection process commenced, depending upon the type of evalution involved, on or about 1 April 1984. An extended version of NOGAPS was run off-time on the operational computers at the Fleet Numerical Oceanography Center (FNOC), Monterey, California. The data collection required the design and regular

execution of several complex computer procedures on the FNOC computers.

The fourth part of this MRFE project consists of evaluating the data saved during the collection phase (part three) and reporting on the MRFE procedures developed and the accuracy and utility of the NOGAPS for medium-range forecasts. This report is the required part four documentation.

The data reduction for part four of the project required that substantial new or greatly modified computer software be prepared. The resultant procedures and computer programs have been turned over to NEPRF for use in subsequent evaluations.

1.2 Period of Evaluation. The NOGAPS forecast fields, derived fields and special forecasts and their verifying analysis fields and synoptic reports were collected during the period 24 March through 15 June 1984. All MRFE associated data were prepared and collected once daily for the 00 GMT synoptic time, since no extended forecasts were prepared with the 12 GMT meteorological data. Details of this collection effort were reported in SASC (1984). In summary:

Field data collection (forecast and verifying analyses) commenced on 24 March and continued through 31 May, but only 30 to 35 actual days of forecasts (depending upon product and length of forecast (TAU)) were prepared, saved and verified. (See subsection 1.3 for a description of certain problems encountered.)

Five-day mean storm track calculations from the standard fields began on 28 March and continued through 15 June, and 57 fields were successfully verified.

Area wind warning calculations began on 25 March and continued through 15 June. Of the resulting wind warning

assessment sets, 53 for five days and 51 for seven days were successfully verified.

Sensible weather forecasting on a twice weekly basis (when possible) commenced 12 April and continued through 9 June. Sixteen 5 and 7 day forecasts were prepared by each of four forecasters and all were verified with observations collected between 17 April and 15 June.

Systematic Error Identification System (SEIS) data collection began on 10 April and continued through 15 June, but only 30 SEIS runs were successfully completed during this 62 day period.

Five-day mean storm track calculations using SEIS output were never prepared as planned, as explained in subsection 2.2.1.1.

1.3 Problems Encountered. As discussed in subsection 1.2, half or more of the potential forecast/verification pairs in certain categories were missed. A sixty-plus day evaluation period succeeded in collecting only about one month's data. This is attributed to the following:

NOGAPS Fields Not Available. NOGAPS fields were not prepared on 30 March, on 9 and 16 April, on 3, 4, 5, 6, 8, 15, 22, and 29 May and on 1 and 7 June (13 days in all). On these days analyses were used to verify previous forecasts, but the missing forecasts were unrecoverable and affected products involving adjacent days (for example, lagged averages). The five days missed in early May were apparently associated with installing a major forecast model change. The reasons for other missed runs included a power outage, late start-early termination, operational priorities, etc.

NOGAPS Model Change. As mentioned above, in early May a major change to the forecast model was installed - not without difficulty. This model change was not well documented, but apparently affected only the day 6 and day 7 (TAU 144 and 168) output. Besides the trauma of implementing the change, it also makes detailed performance statistics and month-to-month comparisons somewhat suspect.

Magnetic Tape Difficulties. Rotating mass storage was not available for storing the many fields and raw verification data required for this evaluation. All such information was routinely written to magnetic tape for further processing or for backup purposes. Many frustrations resulted. First, there was a critical shortage of magnetic tapes at Fleet Numerical Oceanography Center (FNOC) and it became necessary to stack several days data onto one tape rather than keep days separated as planned. Similarly, multi-day collections of verification data had to be stacked. This complex process caused one serious procedural error or oversight which resulted in the loss of field verification statistics for 10 days during late April and early May. Second, at least one physical tape unit at FNOC proved highly unreliable and there were difficulties with some pretested reels of tape. Most of the resulting problems were corrected, but two complete days of basic forecast fields proved unrecoverable (2 and 11 April).

Cancelled or Delayed Jobs. Because the six and seven day forecast fields were not being produced for operational use and because all of the derivations and verifications were of low execution priority, there were frequent cases of late field data availability and of verification jobs being "locked out" for extended periods. In some instances they were simply dropped by the operator in favor of higher priority and/or classified processing. In a very few cases, individual derived products or verifications were never made

as a result, but usually next day or Monday morning recovery was possible. SEIS processing was most seriously affected by classified operations since it required extensive use of the CYBER 170/175 computer.

SECTION 2. FINDINGS

2.1 Field Verifications. The field verification procedures are described in subsection 2.2.1 of the Evaluation Plan. Global forecast fields of height, temperature and wind (u and v components) at four levels (1000, 850, 500 and 200 mb) for four TAU's (96, 120, 144 and 168 hours) were verified. The 1000 and 500 mb fields were also used to derive the non-standard fields specified in Figure 2-01.

In accordance with the Evaluation Plan, field verifications were made and analyzed for April and May and for both months combined, for each of forecast days 4 through 7 (TAUs 96 through 168) in terms of several objective scores for the five major areas and seven subareas listed in Table 1.

TABLE 1. Verification Areas

AREA	COORDINATES	NR. OF STD. GRID POINTS
Northern Hemisphere	20N-80N,60E-0-57.5E	3600
Tropics	20N-20S,60E-0-57.5E	2448
Tropical N. Atlantic	00N-20N,20-90W	261
Tropical W. Pacific	20N-20S,100E-180	1241
North Indian Ocean	00N-20N,60-100E	153
Southern Hemisphere	20S-80S,60E-0-57.5E	3600
North Pacific	70N-20N,120E-120W	1029
Northwest Pacific	70N-20N,120E-180	525
Northeast Pacific	70N-20N,180-120W	525
North Atlantic	70N-20N,80W-10E	777
Northwest Atlantic	70N-20N,80W-35W	399
Northeast Atlantic	70N-20N,35W-10E	399

The North Pacific area approximates the Storm Track and SEIS areas. For area means (see below), a cosine weighting function was used to compensate for the decrease in area as a function of latitude from the equator to either pole.

Mb Level	Derived Field Description	TAU				
		0	96	120	144	168
1000	Time Temperature Range		←	V	→	
1000	Time Wind Direction Range		←	V	→	
1000	Time Wind Magnitude Range		←	V	→	
1000	Lagged Temperature Range			V*		
1000	Lagged Wind Direction Range			V*		
1000	Lagged Wind Magnitude Range			V*		
500	Spectral Height Truncation Waves 1 thru 3	A	V	V	V	V
500	Spectral Height Truncation Waves 4 thru 9	A	V	V	V	V
500	Time Average Height All Waves		←	V	→	
500	Time Average Height Trunc. Waves 1 thru 3		←	V	→	
500	Time Average Height Trunc. Waves 4 thru 9		←	V	→	
500	Lagged Average Height All Waves			V*		
500	Lagged Average Height Trunc. Waves 1 thru 3			V*		
500	Lagged Average Height Trunc. Waves 4 thru 9			V*		
500	Time Temperature Range		←	V	→	
500	Time Wind Direction Range		←	V	→	
500	Time Wind Magnitude Range		←	V	→	
500	Lagged Temperature Range			V*		
500	Lagged Wind Direction Range			V*		
500	Lagged Wind Magnitude Range			V*		

LEGEND:
- A - derived for use as a verifying analysis.
- V - derived from verification.
- V* - derived from the same calendar day and time data from the three most recent daily forecast runs.
- ←V→ - derived from the three TAUs indicated, all from same run.

FIGURE 2-01. Derived Fields

Except as noted, the following objective scores were computed for the basic fields for all areas, levels and variables:

- mean error of forecast (only the wind in the tropics)
- mean error of persistence (wind only, tropics only)
- root-mean-square error of forecast (only the wind in the tropics)
- root-mean-square error of persistence (wind only, tropics only)
- standard deviation of forecast error (only the wind in the tropics)
- standard deviation of persistence error (wind only, tropics only)
- standard deviation of verifying anomaly (heights and temperatures only, not in tropics)
- anomaly correlation of forecast (heights and temperatures only, not in tropics)

These scores were computed using the following expressions:

$$1/n \ \Sigma \ (F-A_v) = (\overline{F-A_v}) = \text{mean error of forecast}$$

$$1/n \ \Sigma \ (A_o-A_v) = (\overline{A_o-A_v}) = \text{mean error of persistence}$$

$$\sqrt{1/n \ \Sigma \ (F-A_v)^2} = \text{rmse of forecast}$$

$$\sqrt{1/n \ \Sigma \ (A_o-A_v)^2} = \text{rmse of persistence}$$

$$\sqrt{1/n\ \Sigma\ [(F-A_v)-(\overline{F-A_v})]^2} = \text{standard deviation of forecast error}$$

$$\sqrt{1/n\ \Sigma\ [(A_o-A_v)-(\overline{A_o-A_v})]^2} = \text{standard deviation of persistence error}$$

$$\sqrt{1/n\ \Sigma\ [(A_v-C)-(\overline{A_v-C})]^2} = \text{standard deviation of verifying anomaly}$$

$$\frac{\{[(F-C)-(\overline{F-C})]\ [(A_v-C)-(\overline{A_v-C})]\}}{\sqrt{[(F-C)-(\overline{F-C})]^2\ [(A_v-C)-(\overline{A_v-C})]^2}} = \text{anomaly correlation for forecast}$$

where:

A_o = initial analysis
A_v = verifying analysis
F = forecast
C = monthly climatology
n = number of gridpoints in the verification area
$F-C$ = predicted anomaly
A_v-C = verifying anomaly
$F-A_v$ = forecast error
A_o-A_v = persistence error
(overbar) $\overline{\quad\quad}$ = area mean

Vector wind ($\vec{V}$) errors were calculated in wind component form as follows:

$$\text{mean error } \vec{V} = \sqrt{[\text{mean error}(u)]^2 + [\text{mean error}(v)]^2}$$

$$\text{rmse}(\vec{V}) = \sqrt{[\text{rmse}(u)]^2 + [\text{rmse}(v)]^2}$$

$$\text{stdv}(\vec{V}) = \sqrt{[\text{stdv}(u)]^2 + [\text{stdv}(v)]^2}$$

Vector wind errors were calculated at 200 mb for both hemispheres and the tropics. Scalar wind direction and magnitude errors were separately calculated for all areas and levels.

In the tropics as a whole and in the three tropical subareas separately, the ability to forecast substantial change in vector wind at 1000 and 200 mb was assessed at each grid point. Substantial change thresholds were set at 10 and 25 kt for the two levels respectively. Contingency tables were then be used to compute error reduction and forecast bias statistics.

The derived fields listed in Figure 2-01 were verified for the two hemispheres and two ocean basins only. These verifications were in terms of mean error of forecast, rmse of forecast and standard deviation of forecast error for the spectral truncations and averages. The derived range fields were verified in terms of percent of points within the specified range at 00 GMT on Day 5.

The complete April, May and two-month combined verification scores were provided to NEPRF under separate cover. These scores are discussed in summary form by level and parameter in subsequent subsections.

2.1.1 Basic Field Skills.

2.1.1.1 1000 Millibar Level.

2.1.1.1.1 Heights. Mean 1000 mb height errors, which are generally positive for most times and TAU's, range from less than 9 m at T96 (TAU 96) to less than 23 m at T168. Exceptions are the consistently negative errors in the April W. PAC (Western Pacific), April S. HEMI (Southern Hemisphere) and May W. ATL (Western Atlantic). The very high positive (20-36 m) mean errors in the May S. HEMI are also noteworthy. RMS (Root-Mean-Square) errors at 1000 mb range from 45 m (May, E. PAC, T96) to 117 m

(May, S. HEMI, T168), but are generally 60-75 m. AC (anomaly correlation) scores range from 0.34 (May, W. ATL, T168) to a high of 0.65 (May, E. ATL, T120), but are generally 0.50-0.60 at T96 and 0.20-0.30 at T168. There is generally a correlation between low RMS and high AC values. There is no apparent correlation between the magnitude of the verifying anomaly and either the RMS or the AC.

<u>2.1.1.1.2 Temperatures</u>. Mean 1000 mb temperature errors are generally negative and less than 1 deg C. Exceptions are the small positive errors during April in W. ATL and during both months in S. HEMI. Larger (nearly 2 degrees) positive mean errors appear only during April in W. PAC at T144 and T168. RMS errors range from 3.3 deg (May, W. PAC, T96) to 10.0 deg (April, W. ATL, T168). AC scores range from 0.12 (May, E. PAC, T168) to 0.58 (May, N. HEMI, T96). There is reasonable correlation between low RMS and high AC values, but no apparent correlation between either score and the magnitude of the verifying anomaly.

<u>2.1.1.1.3 Winds</u>. The directional errors of wind at 1000 mb are large in all areas. RMS errors are generally between 70 and 75 deg at the lower TAU's and between 80 and 85 deg at TAUs 144 and 168. They are 5 to 10 deg higher in the tropics where persistence provided a slightly (5-9 deg RMS) better wind direction forecast than did NOGAPS. The small mean errors of direction, generally negative in April and positive in May, are not considered significant.

The mean scalar wind speed errors are generally less than 2 kt and are positive in April and negative in May. RMS speed errors at 1000 mb are mostly between 7 and 10 kts, slightly higher (10-11 kts) in the S. HEMI and only slightly less at lower TAU's than at higher TAU's. Again, persistence provided a slightly (0.3-0.8 kt RMS) better wind speed forecast than NOGAPS, but such a small difference may not be statistically significant.

Due to a software error (since corrected in the version delivered to NEPRF) the calculations of skill in forecasting substantial (10 kt) changes in 1000 mb wind speed in the tropics were incorrect and the corresponding statistics in the Appendix should be ignored. (The 200 mb values are correct and will subsequently be discussed.)

2.1.1.2 850 mb Level.

2.1.1.2.1 Heights. Mean 850 mb height errors are generally positive and range from up to 11 m at T96 to up to 20 m at T168. As in the case of 1000 mb heights, there are much larger positive (20-37 m) mean errors in the May S. HEMI. Exceptions are the consistently negative errors in the April and May W. PAC and the May W. LANT. RMS errors at 850 mb range from 39 m (May, E. PAC, T96) to 110 m (May, S. HEMI, T168), but are generally 50 - 75 m. AC scores range from 0.18 (May, E. PAC, T168) to 0.67 (May, E. LANT, T120 (same as 1000 mb)), but are generally 0.50-0.60 at T96 and near 0.30 at T168. There is a reasonable correlation between low RMS and high AC, but no correlation between either of these and the magnitude of the anomaly.

2.1.1.2.2 Temperatures. Mean temperature errors at 850 mb are generally negative and and 1 deg or less for the two months combined, but show considerable month-to-month variation. They vary from less than 0.2 deg C for April in the N. HEMI to 1.6 deg or more in May. The opposite is true in the S. HEMI where in April the mean error is in excess of 1 deg at all TAU's, while in May the errors lie between 0.35 and 0.7 deg. RMS temperature errors are slightly higher in both hemispheres in May. They range from 3.1 (May, E. LANT, T96) to 6.2 deg (April, E. PAC, T168). AC scores are in accord by being substantially lower in both hemispheres in May at all TAU's. They range from 0.11 (May, W. LANT, T168) to 0.68 (April, N. HEMI, T96). The N. HEMI anomalies are higher in April, when AC scores are high, than in May when AC scores are lower. The opposite is true in the S.

HEMI. This lack of any consistent correlation between the magnitude of the anomalies and the other scores will not be commented upon further in the following subsections.

2.1.1.2.3 Winds. The mean directional errors of wind at 850 mb are large in all areas except the tropics. They are slightly less than at 1000 mb. RMS errors are generally between 70 and 75 deg at the lower TAU's and between 75 and 80 deg at T144 and T168. The RMS errors are over 90 deg at all TAU's in the tropics where persistence again provided the better forecast by about 5 deg RMS.

Although mean wind speed errors are generally positive and less than 2 kt in April, they are very decidedly negative in May, when mean speed errors are over three knots at higher TAU's. RMS speed errors are mostly between 10 and 13 kts, slightly higher in the S. HEMI and only a knot or two less at T96 than at T168. Again, persistence provided a fractionally better overall forecast than NOGAPS at these time scales.

2.1.1.3 500 mb Level.

2.1.1.3.1 Heights. Mean height errors at 500 mb are generally positive, especially in April. They range from a low of about -1 m to nearly 70 m. RMS errors range from 52 m (May, E. PAC, T96) to 147 m (May, S. HEMI, T168) but most of the errors are generally between 75 and 115 m. AC scores range from 0.07 (May, W. ATL, T168) to 0.77 (May, ATL, T96), but are generally 0.60-0.70 at T96 and 0.30-0.40 at T168. AC scores are nearly always lower in the S. HEMI than in the N. HEMI. There is the usual correlation between RMS and AC scores.

2.1.1.3.2 Temperatures. Mean temperature errors at 500 mb are positive for both months, and all TAU's and levels. They range from 1-2 deg at T96 to 2-3 deg at T168, although they are slightly higher in the S. HEMI. RMS errors range from 2.9 (May,

E. PAC, T96) to 5.5 (May, S. HEMI, T168). AC scores for 500 mb temperatures range from 0.30 (May, E. PAC, T96) to 0.62 (April, E. ATL, T96). There is the customary correlation between higher RMS and lower AC scores.

<u>2.1.1.3.3 Winds</u>. The directional errors of wind at 500 mb lie between 55 and 70 and are about 15 degrees less than at the lower levels. The exception is the tropics where they remain between 80-90 deg and are essentially identical to the error of persistence at all TAU's.

The wind speed mean errors are slightly more negative in May than in April and range between 0 to 4 kt in the former and 2-6 kt in the latter. RMS speed errors are 15-20 kt except for the tropics where they are 8-10 kt, which is slightly less than the persistence forecast for both months at all TAU's.

<u>2.1.1.4 200 mb Level</u>.

<u>2.1.1.4.1 Heights</u>. Mean 200 mb height errors are all positive, are much larger than at 500 mb, and vary little from April to May. They range from 41 m (April, N. HEMI, T96) to 151 m (May, S. HEMI, T168). RMS errors are somewhat higher in April than in May except in the S. HEMI. They range from 98 m (May, E. PAC, T96) to 237 m (May, S. HEMI, T168), but are generally 110-190 m. AC scores range from 0.15 (May, E. PAC, T168) to 0.75 (May, E. ATL, T96), but are generally 0.60-0.70 at T96 and 0.25-0.40 at T168. As expected, the AC scores at all TAU's are lower in the S. HEMI than in the N. HEMI. There is the usual loose correlation between RMS and AC scores.

<u>2.1.1.4.2 Temperatures</u>. Mean temperature errors at 200 mb are generally negative 0.5-1.5 deg. Two exceptions are the E. ATL in April and the W. ATL in May where they were less than 1 deg but positive. RMS errors range from 4-5 deg at T96 to 5-7 deg at T168, which is a degree or so higher than at 500 mb. The

extremes in the AC scores for 200 mb temperatures are found in the same area (E. ATL) with a low of -0.08 (May, T168) and a high of 0.60 (April, T96). The correlation between higher RMS and lower AC is again noted.

2.1.1.4.3 Winds. The 200 mb directional errors lie between 40 and 65 and are 5-10 degrees less than at 500 mb. The exception is again in the tropics, where they remain near 80 deg and are about 5 deg worse (higher) than persistence at all TAU's.

The mean wind speed errors are slightly more negative in May than in April. They range between +2 and -8 in May and between -15 and -7 in April. They are most negative in the tropics in both months. RMS speed errors at 200 mb are 22-27 kt at the lower TAU's and 28-33 kt at the higher TAU's; except in the tropics when they are 5-10 kt less than in other areas and essentially equal to persistence (less than ±1 kt).

Vector winds errors were computed at 200 mb. They lie between 37 kt (T96) and 44 kt (T168) in the N. HEMI. Corresponding figures for the S. HEMI are 43 and 52 kt, and for the tropics they are 32 and 34 kt. The vector errors of persistence in the tropics were 40-41, so the model was clearly better than persistence in this comparison.

The skill of the model in forecasting substantial (25 kt or more) changes in wind speed at 200 mb in the tropics and its three subareas was also assessed. Contingency tables were used to compute the error reduction with respect to the chance of the event occuring in nature and to compute the bias with respect to overforecasting the 25 kt wind speed change event (positive bias) or underforecasting the event (negative bias). The results are presented in Table 2.

TABLE 2. Skill in Forecasting Change (≥25 kt) at 200 mb.

Month	Area	T96	T120	T144	T168
		Error Reduction/Bias			
April	Tropics (all)	.25/-.10	.23/-.03	.21/-.05	.20/-.07
	Trop. N. ATL	.24/-.13	.26/-.03	.29/+.01	.28/-.11
	Trop. W. PAC	.28/-.04	.22/+.01	.15/-.04	.18/-.03
	Trop. Ind. Ocean	.25/-.32	.19/-.40	.15/-.46	.15/-.45
May	Tropics (all)	.22/-.08	.21/-.08	.20/-.09	.20/-.08
	Trop. N. ATL	.23/-.21	.21/-.19	.13/-.21	.12/-.22
	Trop. W. PAC	.22/+.02	.20/+.04	.19/+.05	.22/+.04
	Trop. Ind. Ocean	.11/-.19	.12/-.23	.09/-.11	.18/+.01
Total	Tropics (all)	.24/-.09	.22/-.06	.21/-.07	.20/-.07
	Trop. N. ATL	.24/-.16	.24/-.10	.21/-.09	.22/-.16
	Trop. W. PAC	.25/-.01	.21/+.03	.17/+.00	.20/-.00
	Trop. Ind. Ocean	.18/-.26	.15/-.32	.13/-.33	.15/-.29

Error reduction scores are generally highest in the tropical Atlantic and definitely lowest in the Indian Ocean. The lack of great variation overall between T96 and T168 is noted but cannot be explained. The generally negative bias reflects underforecasting of 25 kt wind speed changes at 200 mb, the principal exception being May in tropical W. PAC.

2.1.2 Derived Field Skills.

2.1.2.1 1000 mb Derived Fields.

2.1.2.1.1 Temperature Ranges. In this verification the ability of the model to forecast the probable range (upper-lower limit) of temperature at T120 was accessed. Ranges were obtained in two ways:

a. By extracting the maximum and minimum values at each grid point for TAUs 96, 120 and 144 in the <u>same forecast run</u> to obtain a T120 <u>Time Range</u>.

b. By extracting the maximum and minimum values from the set of grid point values for TAUs 168, 144 and 120 respectively in three <u>successive</u> 00 GMT <u>forecast runs</u> to obtain a T120 <u>Lagged Range</u>.

If the analyzed value (<u>not</u> the range) at a grid point was within the forecast range, a "hit" or good forecast was recorded. Then the percentage of grid point hits was calculated for the two hemispheres. The results for 1000 mb temperatures for the two months combined are presented below.

RANGE TYPE	HEMISPHERE	PERCENT CORRECT
Time	Northern	31
	Southern	34
Lagged	Northern	36
	Southern	41

Surprisingly, more skill was shown in the S. HEMI than in the N. HEMI. Basic field RMS errors at T120 correlated with the range scores above in April and for both months, but not in May when RMS errors are higher in the S. HEMI. Basic field AC scores at T120 correspond to the range scores in April, but not in May or for both months when the AC scores are higher in the N. HEMI. Interestingly, the lagged ranges are consistently better than the time ranges by about 6 percentage points, but 36-41 percent correct forecast does not indicate a large degree of skill.

<u>2.1.2.1.2 Wind Direction Ranges</u>. Wind direction ranges were calculated and verified as discussed under Temperature Ranges for

all five major areas, with the following results for the two months combined.

RANGE TYPE	AREA	PERCENT CORRECT
Time	N. HEMI	38
	N. PAC	37
	N. ATL	38
	S. HEMI	41
	TROP	21
Lagged	N. HEMI	39
	N. PAC	37
	N. ATL	40
	S. HEMI	42
	TROP	21

The scores correlate well with the T120 RMS scores from the 1000 mb basic field verifications. In this category the lagged ranges are only about one percentage point better on average than the time ranges.

2.1.2.1.3 Wind Speed Ranges. Wind speed ranges were calculated and verified as previously discussed for all five major areas, with the following results for the two months combined.

RANGE TYPE	AREA	PERCENT CORRECT
Time	N. HEMI	42
	N. PAC	43
	N. ATL	43
	S. HEMI	42
	TROP	36
Lagged	N. HEMI	47
	N. PAC	47
	N. ATL	47
	S. HEMI	47
	TROP	38

The scores correlate reasonably well with the T120 RMS scores from the 1000 mb basic field verification except in the Tropics where the generally lower wind speeds account for the lower RMS errors. In this category the lagged ranges are 4 percentage points better on average than the time ranges.

2.1.2.2 500 Millibar Derived Fields.

2.1.2.2.1 Temperature Ranges. The temperature ranges at 500 mb were calculated and verified as they were at 1000 mb (see subsection 2.1.2.1.1). The results for 500 mb temperatures are contained in Table 3.

TABLE 3. Temperature Range Scores.

PERIOD	RANGE TYPE	HEMISPHERE	PERCENT CORRECT
April	Time	Northern	33
		Southern	29
	Lagged	Northern	36
		Southern	32
May	Time	Northern	30
		Southern	29
	Lagged	Northern	39
		Southern	40
Total	Time	Northern	32
		Southern	29
	Lagged	Northern	38
		Southern	37

Except for the May lagged ranges, more skill was shown in the Northern Hemisphere than in the Southern Hemisphere and the

percentages correlate well with the basic field RMS scores. The lagged range scores are about 7 percentage points better on average than the time ranges.

2.1.2.2.2 Wind Direction Ranges. Wind direction ranges were calculated and verified as previously discussed for all five major areas and the results are presented below.

RANGE TYPE	AREA	PERCENT CORRECT
Time	N. HEMI	52
	N. PAC	51
	N. ATL	52
	S. HEMI	53
	TROP	27
Lagged	N. HEMI	55
	N. PAC	54
	N. ATL	55
	S. HEMI	55
	TROP	31

The scores correlate well with the T120 RMS scores from the 1000 mb standard field verifications where the tropical RMS errors were 20 degrees greater than in the other major areas. In this category the lagged ranges are 3 percentage points better on average than the time ranges.

2.1.2.2.3 Wind Speed Ranges. Wind speed ranges at 500 mb were calculated and verified as previously explained, with the following results for the two months combined.

RANGE TYPE	AREA	PERCENT CORRECT
Time	N. HEMI	38
	N. PAC	39
	N. ATL	38
	S. HEMI	41
	TROP	36

RANGE TYPE	AREA	PERCENT CORRECT
Lagged	N. HEMI	43
	N. PAC	44
	N. ATL	44
	S. HEMI	48
	TROP	43

Again, scores tend to be lower in the tropics. In this category the lagged ranges verified higher than the time ranges by nearly 7 percentage points.

2.1.2.2.4 Height Truncations. Spectral representations of the 500 mb height fields were prepared for both analyses and forecasts and the wave number (WN) 1 through 3 and WN 4 through 9 fields were compared. This was done for both hemispheres and for both ocean basins.

RMS errors in each spectral band generally range from about 50 m at T96 to near 70 m at T168 in the Northern Hemisphere, are somewhat higher in the Southern Hemisphere, and are more often lower in magnitude at the higher wave numbers. However, the expected superiority in the lower (1-3) wave number forecasts clearly surfaces when one considers AC scores. WN 1-3 AC scores average 0.12 higher than those for WN 4-9, except during May when the higher WN forecasts in the S. HEMI had a higher AC.

2.1.2.2.5 Height Averages. In this verification, averages of multiple height forecasts were constructed and compared to observed values of 500 mb surface height. These averages were calculated in two ways:

a. By averaging the individual grid point values for TAUs 96, 120 and 144 in the same forecast run to obtain a T120 Time Average.

b. By averaging the individual grid point values for TAUs

168, 144 and 120 respectively in three successive 00 GMT forecast runs to obtain a T120 Lagged Average.

Both of these T120 averages were constructed from the 500 mb height fields for WN 1-3, WN 4-9 and the complete untruncated field for both hemispheres and the two ocean basins. RMS errors for the truncations were 56-66 m in April and 36-66 m in May. RMS scores for the untruncated fields were 30-40 m larger getting as high as 117 m in the S. HEMI in May.

AC scores are the more interesting and are summarized in Table 4.

TABLE 4. 500 mb Anomaly Correlation (AC) Scores.

			AC SCORE (X 100)		
MONTH	WAVE NUMBER	AREA	UNAVERAGED	TIME AVERAGE	LAGGED AVERAGE
April	1-3	N. HEMI	63	63	67
		N. PAC	68	69	72
		N. ATL	62	63	60
		S. HEMI	58	61	57
	4-9	N. HEMI	49	49	53
		N. PAC	52	50	55
		N. ATL	50	51	59
		S. HEMI	47	52	40
	ALL	N. HEMI	57	58	61
		N. PAC	55	64	66
		N. ATL	57	58	61
		S. HEMI	57	57	49

TABLE 4. 500 mb Anomaly Correlation (AC) Scores (continued).

MONTH	WAVE NUMBER	AREA	AC SCORE (X 100) UNAVERAGED	TIME AVERAGE	LAGGED AVERAGE
May	1-3	N. HEMI	64	64	68
		N. PAC	71	71	74
		N. ATL	61	62	68
		S. HEMI	45	41	52
	4-9	N. HEMI	57	57	61
		N. PAC	57	56	59
		N. ATL	61	59	62
		S. HEMI	51	50	58
	ALL	N. HEMI	66	62	66
		N. PAC	63	61	66
		N. ATL	72	68	73
		S. HEMI	54	44	53
Average			58.2	57.9	60.8

There appears little to choose between the unaveraged forecasts and the time averages. The lagged averages are clearly superior to the other two, with the exception of the low lagged averaged score in the S. HEMI for April.

2.2 Special Verifications.

2.2.1 Mean Storm Track.

2.2.1.1 Evaluation Procedure. The NOGAPS sea level pressure fields for TAUs 72, 96, 120, 144 and 168 were used to create a five-day, centered on day five, composite storm track field over the greater North Pacific. The area is the same 26 x 31 subset of the standard FNOC 63 x 63 Northern Hemisphere polar

stereographic grid used by the SEIS for vortex tracking in the Pacific (see Figure 2-02). The five verifying analysis fields were also composited and the resultant storm track analysis field was used to compute a correlation coefficient between forecast and verifying fields.

Composites were constructed by removing the zonal mean from each grid point in each forecast sea level pressure field. Next, a value of one was assigned to any grid point whose initial value exceeded the zonal mean. Finally, the lowest of the five time values at each grid point was assigned to the corresponding composite grid point. Figure 2-03 shows the forecast composite and verifying composite for a typical five-day mean storm track centered on 17 April 1984 (i.e., using TAU 72, 96, ... 168 forecast fields prepared from 00 GMT data on 12 April and 00 GMT analysis fields from 15 through 19 April).

The Evaluation Plan stated that composites would also be constructed from the SEIS vortex tracking program's lows-only output. This was not done because substantial changes to the vortex tracking program were in progress and the required NEPRF personnel were not available.

2.2.1.2 Results. Fifty-seven five-day composite storm track forecast fields were verified. The first was prepared on 28 March (for the five day period 31 March through 4 April) and the last was prepared on 8 June (for the period 11-15 June). The highest correlation coefficient (0.84) was for the composite forecast prepared on 30 May (see Figure 2-04). The lowest (0.44) was for the 21 May forecast (see Figure 2-05). The mean correlation coefficient was 0.66 with a standard deviation of 0.08. Figure 2-06 is a plot of all 57 correlations.

The considerable variation in scores indicates the ability of this evaluation method to discriminate between "good" and "bad" forecasts of mean storm track. One also notes episodes of

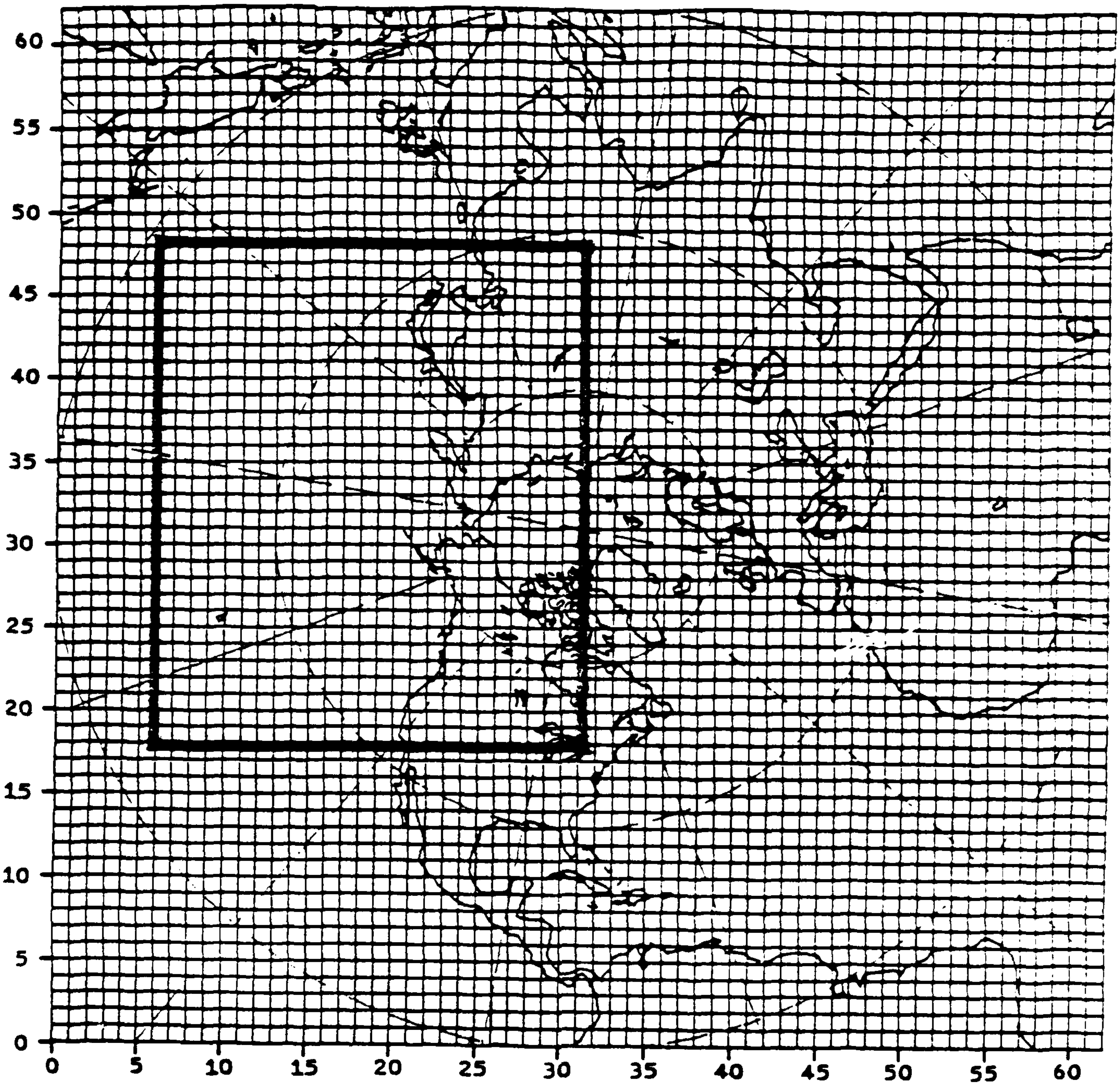
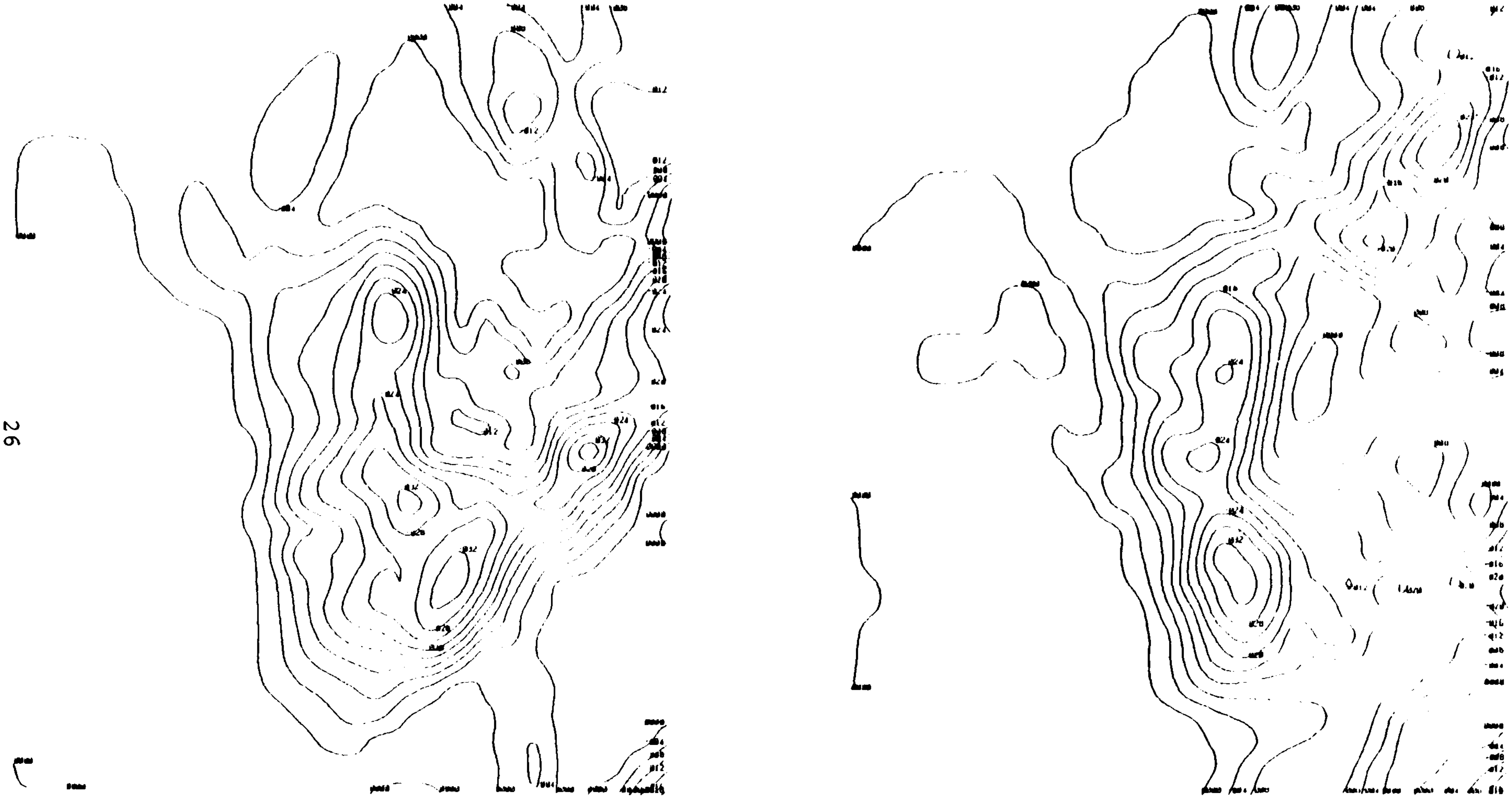


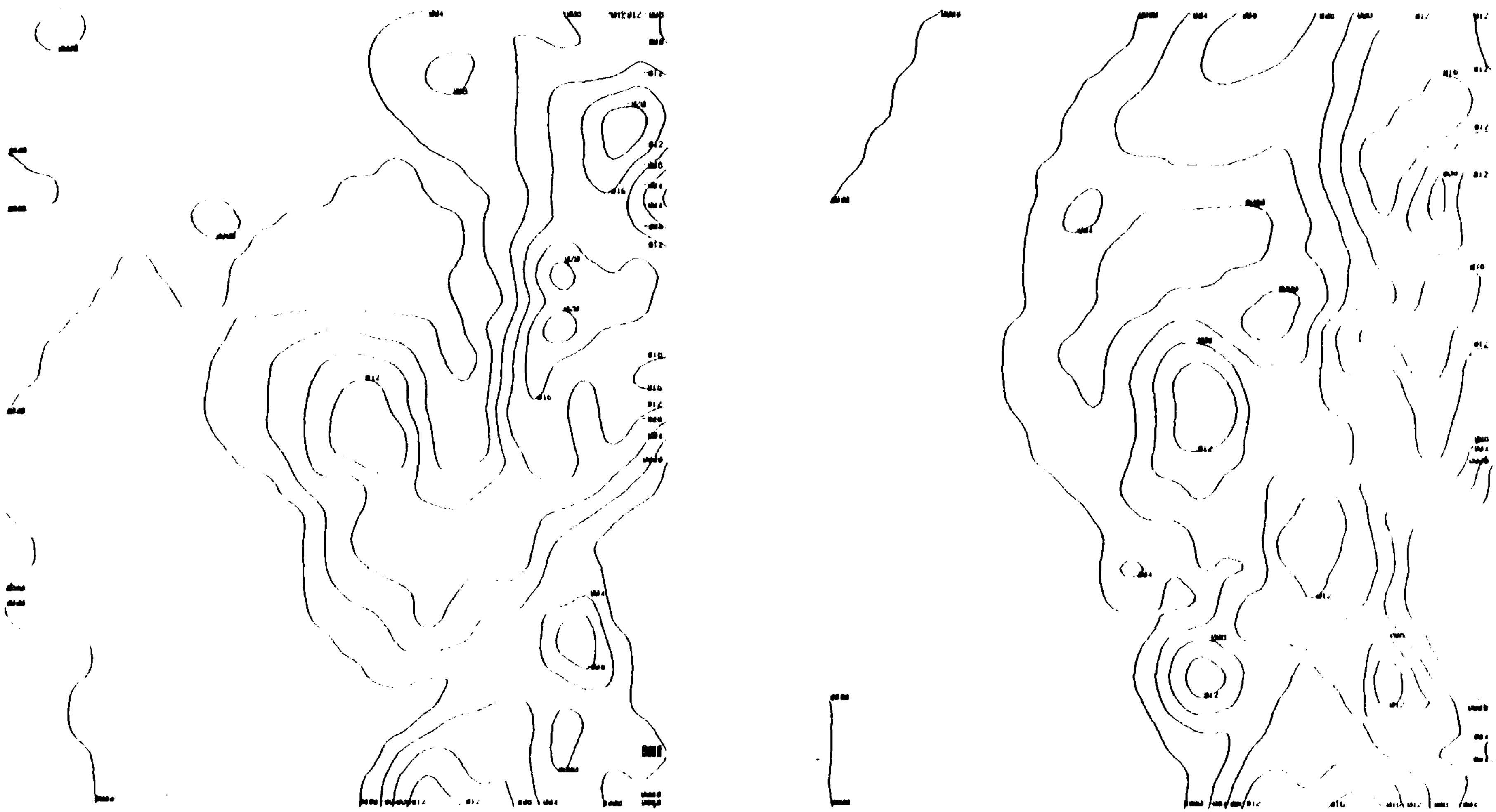
FIGURE 2-02. The 63x63 Northern Hemisphere Polar Stereographic Grid and the 26x31 Subset used for Storm Track Verification.



a. Forecast Field

b. Verifying Field

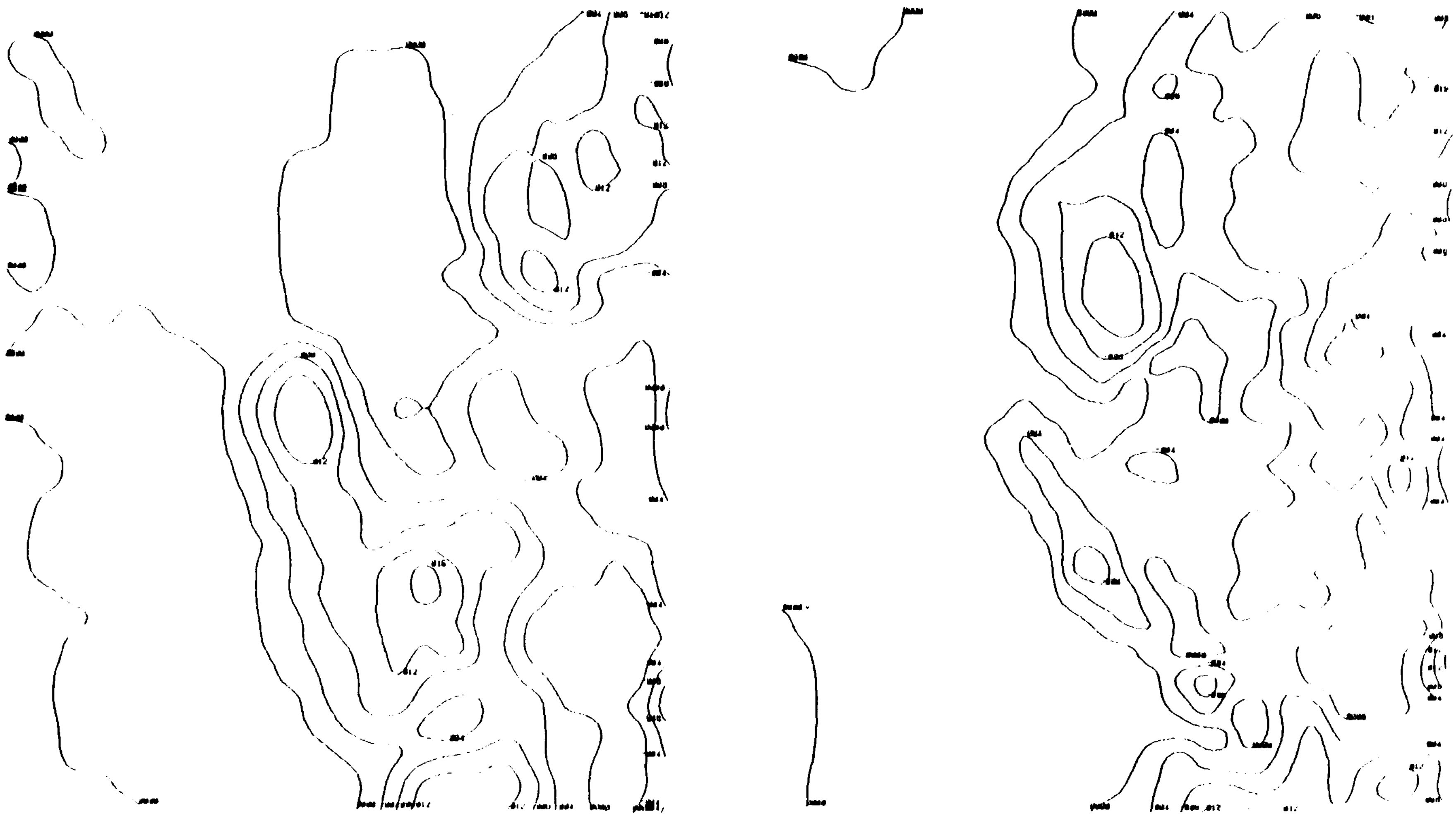
FIGURE 2-03. Composite storm track verification for 12/17 April (Corr. Coeff. 0.66).



a. Forecast Field

b. Verifying Field

FIGURE 2-04. Composite storm track verification for 30 May/4 June (Corr. Coeff. 0.84).



a. Forecast Field

b. Verifying Field

FIGURE 2-05. Composite storm track verification for 21/26 May (Corr. Coeff. 0.44).

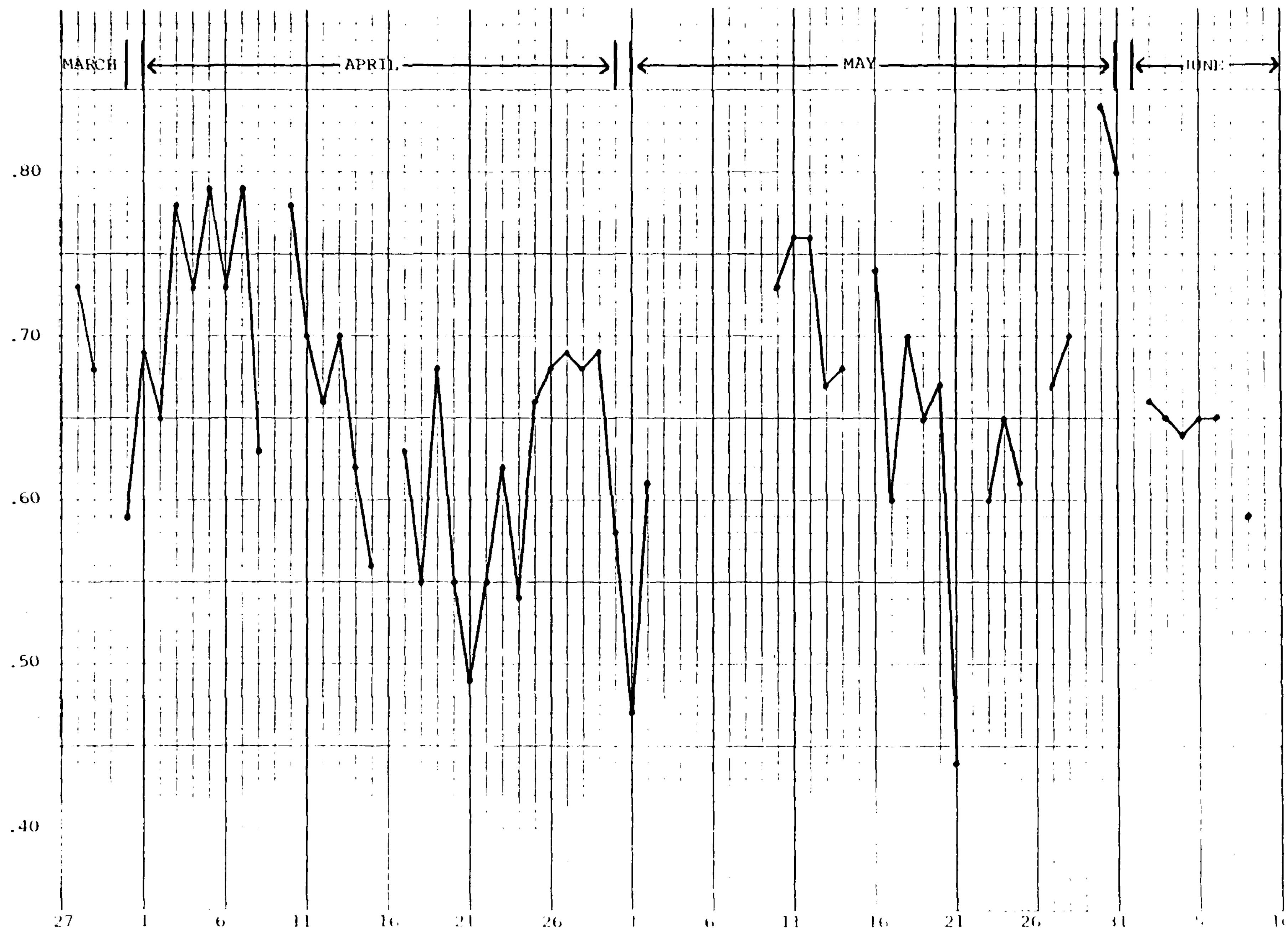


FIGURE 2-06. Daily variation of the mean storm track correlation coefficients (5 day 00Z means (entered on the forecast base date (shown) plus 5 days)).

high and low predictability (for example, 3-7 and 20-24 April respectively). Month-to-month variations were modest, however. The mean correlation coefficient for April was 0.66 and for May it was 0.67.

2.2.2 Area Wind Warnings.

2.2.2.1 Evaluation Procedure. The NOGAPS five- and seven-day 1000 mb wind fields (u and v) were used to determine if gale force winds (greater than 32 knots) were likely over any of eight 7.5 degree latitude by 15 degree longitude ocean areas (four in the North Pacific and four in the North Atlantic). The area locations and the gale yes-or-no selection and scoring criteria as specified in subsection 2.1.2.2 of the Evaluation Plan were as follows:

- Location of areas:
  - 52.5-60.0N/15.0-30.0W and 175E-170W
  - 42.5-50.0N/35.0-50.0W and 155-170E
  - 32.5-40.0N/60.0-75.0W and 140-155E
  - 22.5-30.0N/15.0-30.0W and 150-165W

  (Eight areas, all elongated in the east-west direction and favoring the preferred storm tracks.)

- Forecast Variables:
  - Gale force or stronger winds in area on day 5 - yes or no
  - Gale force or stronger winds in area on day 7 - yes or no

- Selection Criteria:
  - Yes if 10 or more of the 28 grid points within or on the perimeter of the area are forecast to have winds in excess of 32 knots at 00 GMT.
  - No if less than 10 grid points meet the above criterion.

(Ten grid points define about 25 percent of the area if contiguous. This less-than-50 percent criterion is conservative and provides some allowance for any phase error.)

- Scoring Criteria (verification):
  - If gale forecast was yes:

    $\geq$ 10 points $\geq$ 30 knots = 100%
    9 points $\geq$ 30 knots = 90%
    8 points $\geq$ 30 knots = 80%
    etc.
    0 points $\geq$ 30 knots = 0%

  - If gale forecast was no:

    $\leq$ 9 points $\geq$ 36 knots = 100%
    10 points $\geq$ 36 knots = 90%
    11 points $\geq$ 36 knots = 80%
    etc.
    $\geq$ 19 points $\geq$ 36 knots = 0%

  (The 30 and 36 knot yes/no verification criteria are purposely in the "model's" favor.)

This area wind warning evaluation commenced on 25 March and continued, subject to forecast and verifying field availability, through 10 June 1984. Fifty-three five day and 51 seven day NOGAPS forecast fields were verified for each of the eight areas.

2.2.2.2 Results. Individual area contingency tables are presented in relative plan view for each ocean in Figures 2-07 and 2-08. Ocean basin and all-area summaries are provided in Figure 2-09. The latter figure also shows three contingency tables at the bottom which derive from a more straight-forward 33 and 33 kt scoring criteria than the 30 and 36 kt criteria as in subsection 2.2.2.1. The three tables at the bottom of Figure 2-09 consider only the forecast and/or observation of 10 or more

AREA P1 (60.0N–52.5N, 175E–170W)

OBSERVED \ FORECAST	YES	NO
YES	Count: 1 2 Avg %: 100 100	Count: 1 3 Avg %: 80 50
NO	Count: 3 1 Avg %: 57 30	Count: 48 45 Avg %: 100 100

AREA P2 (50.0N–42.5N, 155E–170E)

OBSERVED \ FORECAST	YES	NO
YES	Count: 1 0 Avg %: 100 ---	Count: 1 1 Avg %: 10 10
NO	Count: 1 3 Avg %: 10 10	Count: 50 47 Avg %: 100 100

AREA P3 (40.0N–32.5N, 140E–155E)

OBSERVED \ FORECAST	YES	NO
YES	Count: 0 0 Avg %: --- ---	Count: 0 0 Avg %: --- ---
NO	Count: 6 3 Avg %: 22 17	Count: 47 48 Avg %: 100 100

AREA P4 (30.0N–22.5N, 165W–150W)

OBSERVED \ FORECAST	YES	NO
YES	Count: 0 0 Avg %: --- ---	Count: 0 0 Avg %: --- ---
NO	Count: 0 0 Avg %: --- ---	Count: 53 51 Avg %: 100 100

FIGURE 2-07. N. Pacific Wind Warning Areas and Scores (five day first, seven day second)

AREA A1 (60.0N – 52.5N, 30W – 15W)

OBSERVED	FORECAST YES	FORECAST NO
YES	Count: 1 0 Avg %: 100 ---	Count: 2 1 Avg %: 45 70
NO	Count: 0 5 Avg %: --- 52	Count: 50 45 Avg %: 100 100

AREA A2 (50.0N – 42.5N, 50W – 35W)

OBSERVED	FORECAST YES	FORECAST NO
YES	Count: 1 0 Avg %: 100 ---	Count: 1 2 Avg %: 60 80
NO	Count: 6 3 Avg %:	Count: 45 46 Avg %: 100 100

AREA A3 (40.0N – 32.5N, 75W – 60W)

OBSERVED	FORECAST YES	FORECAST NO
YES	Count: 0 0 Avg %: --- ---	Count: 0 0 Avg %: --- ---
NO	Count: 2 0 Avg %: 50 ---	Count: 51 51 Avg %: 100 100

AREA A4 (30.0N – 22.5N, 30W – 15W)

OBSERVED	FORECAST YES	FORECAST NO
YES	Count: 0 0 Avg %: --- ---	Count: 0 0 Avg %: --- ---
NO	Count: 0 0 Avg %: --- ---	Count: 55 54 Avg %: 100 100

FIGURE 2-08. N. Atlantic Wind Warning Areas and Scores (five day first, seven day second)

N. PACIFIC AREAS

OBSERVED \ FORECAST	YES	NO
YES	Count: 2 2 Avg %: 100 100	Count: 2 4 Avg %: 45 40
NO	Count: 10 7 Avg %: 31 16	Count: 198 191 Avg %: 100 100

N. ATLANTIC AREAS

OBSERVED \ FORECAST	YES	NO
YES	Count: 2 0 Avg %: 100 ---	Count: 3 3 Avg %: 50 --
NO	Count: 8 8 Avg %: 50 53	Count: 199 193 Avg %: 100 100

ALL AREAS

OBSERVED \ FORECAST	YES	NO
YES	Count: 4 2 Avg %: 100 100	Count: 5 7 Avg %: 48 56
NO	Count: 18 15 Avg %: 39 35	Count: 397 384 Avg %: 100 100

N. PACIFIC AREAS

OBSERVED \ FORECAST	YES	NO
YES	Count: 1 0	Count: 4 5
NO	Count: 10 9	Count: 197 190

N. ATLANTIC AREAS

OBSERVED \ FORECAST	YES	NO
YES	Count: 2 0	Count: 5 7
NO	Count: 8 9	Count: 197 188

ALL AREAS

OBSERVED \ FORECAST	YES	NO
YES	Count: 3 0	Count: 9 12
NO	Count: 18 18	Count: 394 378

FIGURE 2-09. Wind Warning Summary Scores (30 and 36 knot criteria at top, 33 and 33 knot criteria at bottom; five day counts first, seven day counts second)

grid points within an individual area with 33 kt or more of wind. Since this eliminates certain adjustments made in the 30-36 kt scheme which favors the model, a decrease in "correct" forecasts is apparent.

Of the 12 "observed gales" (10 or more of the 28 grid points within the warning area with more than 32 knots in the verifying analysis) 10 occurred in April. All 12 gales occurred in the four higher latitude areas. Thus, about half of the forecasts and half of the areas never really came into play.

Less than half of the actual gales were forecast by the liberal 30-36 kt criteria (4 of 9 at day five and only 2 of 9 at day seven) and far fewer by the 33-33 kt criteria (only 3 of 12 at day five and none at day seven).

The all-area false-alarm rate varied from a <u>low</u> of 82% (day five, 30-36 kt criteria) to 100% (day seven, 33-33 kt criteria).

Table 5 provides threat and Heidke skill scores for the six sets of summary data.

TABLE 5. Gale Forecasting Skill Summary.

FIVE DAY FORECASTS	THREAT SCORE	ADJUSTED THREAT SCORE[1]	HEIDKE SKILL SCORE
N. Pacific Areas (30-36 kt criteria)	0.143	0.126	0.228
N. Atlantic Areas (30-36 kt criteria)	0.154	0.134	0.243

[1] Adjusted Threat Score (ATS) is derived from the standard threat score (TS) as follows:

$$ATS = \frac{TS - (\text{observed occurrences}/\text{possible occurrences})}{1 - (\text{observed occurrences}/\text{possible occurrences})}$$

TABLE 5. Gale Forecasting Skill Summary (continued)

FIVE DAY FORECASTS	THREAT SCORE	ADJUSTED THREAT SCORE[1]	HEIDKE SKILL SCORE
All Areas (30-36 kt criteria)	0.148	0.130	0.235
N. Pacific Areas (33-33 kt criteria)	0.067	-0.044	0.097
N. Atlantic Areas (33-33 kt criteria)	0.133	0.104	0.204
All Areas (33-33 kt criteria)	0.100	0.074	0.151
SEVEN DAY FORECASTS			
N. Pacific Areas (30-36 kt criteria)	0.154	0.128	0.240
N. Atlantic Areas (30-36 kt criteria)	0.000	-0.015	-0.022
All Areas (30-36 kt criteria)	0.083	-0.062	0.129
N. Pacific Areas (33-33 kt criteria)	0.000	-0.025	-0.033
N. Atlantic Areas (33-33 kt criteria)	0.000	-0.036	-0.040
All Areas (33-33 kt criteria)	0.000	-0.030	-0.037

[1] Adjusted Threat Score (ATS) is derived from the standard threat score (TS) as follows:

$$\text{ATS} = \frac{\text{TS} - (\text{observed occurrences}/\text{possible occurrences})}{1 - (\text{observed occurrences}/\text{possible occurrences})}$$

By all of the above measures, the model's ability to forecast gales during the evaluation was marginal for day five and essentially non-existent for day seven. Somewhat more

encouraging results are obtained, however, when one considers only the higher latitude areas. For example, the scores for the two most northerly Pacific areas (P1 and P2) combined using 30-36 kt criteria are:

	THREAT SCORE	ADJUSTED THREAT SCORE	HEIDKE SKILL SCORE
Five Day Forecasts:	0.25	0.22	0.37
Seven Day Forecasts:	0.20	0.15	0.29

In addition to the high false-alarm rates cited earlier, the larger number of over forecasts (forecast yes - observed no) than under forecasts (forecast no - observed yes) and the generally lower over forecast percentage (Avg %) scores both indicate a decided model tendency to generate overly strong winds at 1000 mb in middle latitudes. All but one of the false alarms occurred in March or April. In April the mean 1000 mb wind speed errors at TAUs 120 and 168 were 2.1 and 1.3 kt respectively. Corresponding scores for the Atlantic were +0.9 and +0.6.

2.2.3 Subjective Sensible Weather Forecasts.

2.2.3.1 Evaluation Procedure. Selected NOGAPS analysis and forecast fields (those identified with P notation in Table 2-01 of the Evaluation Plan) were plotted, when available, and displayed, together with recent synoptic reports, each Monday through Friday. They were used as guidance to prepare five- and seven-day forecasts of several operationally significant sensible weather parameters. The parameters and other details concerning this part of the evaluation are discussed in subsection 2.1.2.3 of the Evaluation Plan.

The nine forecast locations chosen are listed in the following table:

AREA	LOCATION	BLOCKSTATION NR.
NE Pacific	Kodiak, Alaska	70350
	Adak, Alaska	70454
	Astoria, Oregon	72791
NW Atlantic	Sable Island, Canada	71600
	Key West, Florida	72201
	Hatteras, No. Carolina	72304
NE Atlantic	Valencia, Ireland	03953
	Keflavik, Iceland	04018
	La Coruña, Spain	08001

A total of 16 five- and 16 seven-day forecasts were prepared for each location - the first on 12 April and the last on 8 June. It was planned that sensible weather forecasts would be prepared on Tuesdays and Thursdays, thus permitting comparisons of each Tuesday seven-day forecast with a Thursday five-day forecast verifying at the same time. Unfortunately, various problems involving the model and computer availability usually caused one day or the other to be missed and only 3 of 8 potential Tuesday-Thursday pairs were realized.

The questionnaire shown in Figure 2-10 was used to obtain pre-evaluation period information from individual forecasters. All of the participants were experienced Navy aviation and marine weather forecasters, but none were currently or recently active. Individual experience levels ranged from eight to 17 years. All but one of the four had a degree in meteorology (one BS, one MS and one PhD) and the non-degree forecaster had completed graduate courses in meteorology. Forecaster familiarity with assigned areas and stations varied from nil in one case, through "very familiar" with one of three assigned stations and "somewhat familiar" with the others, to very familiar with the entire area. One of the four forecasters was very familiar with the NOGAPS model output prior to the evaluation and had been working with it on a nearly daily basis for many months. Two of the other three forecasters were totally unfamiliar with NOGAPS output prior to

MEDIUM-RANGE FORECAST EVALUATION (MRFE) FORECASTER QUESTIONNAIRE

NAME: ____ DATE: __________

ORGANIZATION: ____

MOST SIGNIFICANT EDUCATION AND/OR TRAINING IN ATMOSPHERIC SCIENCE: ____

____

____

YEARS AND TYPE OF WEATHER FORECASTING EXPERIENCE: ______________

____

____

____

AREA ASSIGNED FOR MRFE: ____

BLOCK STATIONS AND/OR SUBAREA(S) SELECTED: ______________________

____

TO WHAT DEGREE WERE YOU FAMILIAR WITH YOUR AREA AND STATIONS PRIOR TO THE MRFE? ____

____

____

____

TO WHAT DEGREE WERE YOU FAMILIAR WITH THE NOGAPS MODEL OUTPUT PRIOR TO THE MRFE? ____

____

____

____

FIGURE 2-10. First page of the Medium-Range Forecast Evaluation (MRFE) Forecaster Questionnaire.

the evaluation. The fourth was familiar with the model, but had never used the output to forecast.

2.2.3.2 Results. Verifications of the sensible weather forecasts, including ITCZ forecasts, are discussed below on a variable-by-variable basis. With two minor exceptions, all non-ITCZ scoring was as specified in Table 2-03 of the Evaluation Plan (reproduced here as Figure 2-11). The exceptions (Rain or Shower and Frozen Precipitation) are noted within the parameter results discussion.

2.2.3.2.1 Winds >25 kt - yes/no. The results of the verification are presented in Table 6. (Y/Y is greater than 25 kt forecast (yes) and Verified (yes), Y/N is greater than 25 kt forecast (yes) but not verified (no), N/N is not forecast and not verified, etc.)

TABLE 6. Skill in Forecasting Surface Wind >25 kt.

	FORECAST/VERIFICATION COUNTS											
	FIVE-DAY FCSTS				SEVEN-DAY FCSTS				ALL FORECASTS			
LOCATION	Y/Y	N/N	Y/N	N/Y	Y/Y	N/N	Y/N	N/Y	Y/Y	N/N	Y/N	N/Y
Kodiak	---	16	---	---	---	15	1	---	---	31	1	---
Adak	---	14	2	---	1	14	1	---	1	28	3	---
Astoria	---	16	---	---	---	16	---	---	---	32	---	---
All NE PAC	---	46	2	---	1	45	2	---	1	91	4	---
Sable Island	---	15	---	1	---	14	2	---	---	29	2	1
Key West	---	16	---	---	---	16	---	---	---	32	---	---
Hatteras	---	16	---	---	---	15	1	---	---	31	1	---
All NW ATL	---	47	---	1	---	45	3	---	---	92	3	1
Valencia	---	16	---	---	---	14	2	---	---	30	2	---
Keflavik	---	15	1	---	---	16	---	---	---	31	1	---
La Coruña	---	16	---	---	---	16	---	---	---	32	---	---
All NE ATL	---	47	1	---	---	46	2	---	---	93	3	---
TOTAL	---	140	3	1	1	136	7	---	1	276	10	1

PARAMETER	SCORING RULES
Winds ≥ 25 Ks	If fcst yes: any 18-06Z report ≥ 20 scores 1, otherwise 0 If fcst no: any 18-06Z report ≥ 30 scores 0, otherwise 1
Avg Sfc Wind Spd	Fcst value - avg of 18-06Z reports = score (with sign)
Avg Sfc Wind Dir	If fcst quadrant = geometric avg of 18-06Z score 1, otherwise 0
Sfc Air Temp	Fcst value - avg of 21Z-03Z reports (deg F) = score (with sign)
Avg Cloudiness	Fcst value - avg of 18-06Z total reported clouds (N) = score (with sign)
Lowest Cloud Base	Fcst value - avg of 18-06Z reported bases (h as "plotted") = score (with sign)
Precip Expected	If fcst yes: any 18-06Z ww>49 or any 21-06Z W>4 scores 1, otherwise 0 If fcst no: more than one 18-06Z ww>49 or 21-06Z W>4 scores 0, otherwise 1
Rain or Shower	If precip score = 0 this score is N (null) If precip score = 1 and precip fcst was no, this score is N Otherwise: 18-06Z avg of ww>49 and (Wx10)>40 = PTA Then: If fcst was rain and PTA<77 score 1 If fcst was shower and PTA>78 score 1 Otherwise score 0
Frozen	If precip score = 0 this score is N (null) If precip score = 1 and precip fcst was no, this score is N Otherwise if fcst yes: any 18-06Z ww 56-57, 66-79, 83-90 or 93-97 or 99 or any 21-06Z W of 7 scores 1, otherwise 0. if fcst no: less than two of the above scores 1, otherwise 0
Sfc Visibility	If fcst was yes and any 21-03Z coded VV<56 (≲4 mi) score 1 If fcst was no and all 21-03Z coded VV>35 (≳2½ mi) score 1 Otherwise score 0

FIGURE 2-11. Sensible Weather Forecast Scoring Criteria

As in the area wind warning verification discussed in subsection 2.2.2, these results reflect a near total absence of strong winds for the Northern Hemisphere middle latitudes during this spring evaluation. Ten false alarms (Y/N), one strong wind event correctly forecast (Y/Y) and one event missed (N/Y) are not a statistically sufficient sample from which to assess skill, although the tendency to over-forecast a strong wind event is apparent.

<u>2.2.3.2.2 Average Surface Wind Speed</u>. The results of this verification are presented in Table 7.

TABLE 7. Surface Wind Speed Forecasting Skill.

	MEANS/STANDARD DEVIATIONS (KT)			
	DAY FIVE		DAY SEVEN	
LOCATION	OBSERVED	ERROR	OBSERVED	ERROR
Kodiak	10.4/3.0	-0.6/4.4	10.2/4.7	-1.1/5.9
Adak	9.3/4.1	+1.6/5.2	8.2/4.0	+2.9/5.6
Astoria	8.6/1.5	-0.4/2.4	9.7/1.7	-1.9/3.8
All NE PAC	9.5/3.1	+0.6/4.3	9.4/3.8	-0.0/5.6
Sable Island	13.9/7.2	-0.1/8.6	10.4/2.7	+2.5/5.6
Key West	9.3/1.5	-2.6/3.9	8.4/3.6	-2.8/4.2
Hatteras	8.9/2.1	+1.5/4.7	9.7/3.1	+1.3/7.0
All NW ATL	10.7/5.0	-1.1/6.2	9.5/3.3	+0.5/6.0
Valencia	5.8/3.9	+4.7/4.7	9.5/5.4	+2.1/8.4
Keflavik	9.1/4.4	+2.8/7.0	8.6/4.1	+3.3/5.4
La Coruña	5.6/4.2	-0.6/4.0	4.8/4.2	+0.0/6.5
All NE ATL	7.0/4.5	+2.4/5.7	7.5/5.0	+1.8/7.0
TOTAL	9.0/4.5	+0.5/5.6	8.8/4.2	+0.8/6.3

From the observed averages and standard deviations (SD) one sees that winds were generally low - between 5 and 15 knots, except for Sable Island where they were a few knots higher and La Coruña where they were lower. Average errors were small but not indicative of any particular skill when one considers the standard deviation (SD) of the error. In all but one case (La Coruna - Day Five) the error SD is greater than the observed SD which may mean that always forecasting the "average" wind speed would have shown more skill. To satisfy the acceptable levels of accuracy specified in Table 1-01 of the evaluation plan, the error SD should be about 25 to 35% of the observed SD.

2.2.3.2.3 Average Surface Wind Direction (quadrant). The results of this verification are presented in Table 8.

TABLE 8. Surface Wind Direction Forecasting Skill.

	COUNTS								
	DAY FIVE			DAY SEVEN			ALL FORECASTS		
LOCATION	HIT	MISS	NULL	HIT	MISS	NULL	HIT	MISS	NULL
Kodiak	4	12	--	2	14	--	6	26	--
Adak	5	11	--	4	12	--	9	23	--
Astoria	4	12	--	4	12	--	8	24	--
All NE PAC	13	35	--	10	38	--	23	73	--
Sable Island	3	13	--	2	14	--	5	27	--
Key West	5	11	--	4	11	1	9	22	1
Hatteras	5	10	1	3	13	--	8	23	1
All NW ATL	13	34	1	9	38	1	22	72	2
Valencia	3	13	--	6	9	1	9	22	1
Keflavik	6	10	--	6	10	--	12	20	--
La Coruña	7	6	3	5	2	9	12	8	12
All NE ATL	16	29	3	17	21	10	33	50	13
TOTAL	42	98	4	36	97	11	78	195	15

Ignoring the nulls which resulted from calm wind forecasts, only 29 percent (78/273) of the forecasts were correct. The five-day forecasts were only marginally better than the seven-day (30% versus 27%). Since any observed average direction within 45 degrees of the forecast average direction was considered correct, these results are far from encouraging. In only one instance (La Coruña) did the number of correct forecasts exceed the number incorrect. These results do not satisfy the day-five level of accuracy specified in Table 1-01 of the evaluation plan.

2.2.3.2.4 Surface Air Temperature. The results of this verification are presented in Table 9.

TABLE 9. Surface Air Temperature Forecasting Skill.

	MEANS/STANDARD DEVIATIONS (Deg. F)			
	DAY FIVE		DAY SEVEN	
LOCATION	OBSERVED	ERROR	OBSERVED	ERROR
Kodiak	46.1/8.5	-1.6/5.8	47.3/5.6	-1.4/5.7
Adak	42.9/3.8	-3.2/3.4	45.2/4.7	-4.0/4.0
Astoria	54.6/4.7	-3.4/5.5	53.6/4.0	-1.6/4.8
All NE PAC	48.1/7.8	-2.7/5.1	48.9/6.0	-2.7/4.8
Sable Island	45.1/5.2	+3.8/8.9	45.7/5.0	+2.1/9.2
Key West	78.4/2.3	-0.1/3.6	78.5/2.3	+0.1/3.5
Hatteras	67.7/6.3	-1.9/7.5	67.3/6.7	-2.6/9.2
All NW ATL	63.2/14.9	-1.3/6.5	63.3/14.7	-1.7/7.8
Valencia	48.8/5.5	+1.3/3.2	51.2/4.8	-0.6/4.9
Keflavik	40.9/5.2	-0.6/4.2	41.1/4.6	+0.9/4.5
La Coruña	53.4/4.0	-0.9/3.9	54.4/4.3	+0.8/5.2
All NE ATL	47.7/9.0	-0.1/3.9	48.9/7.3	-0.0/4.9
TOTAL	51.5/9.8	-0.7/5.8	53.8/11.0	-0.9/6.2

Comparing standard deviations (SD), one sees that the error SD are higher than for the observations at 4 of 9 locations on Day Five and at 7 of 9 at Day Seven. Assuming that the SD observed over the eight weeks of forecasting fairly represents the Seasonal Standard Deviation specified in Table 1-J1 of the Evaluation Plan, it is clear that the acceptability criteria of Ø.4 at Day Five and approximately Ø.6 at Day Seven were not achieved. The best at Day Five was Ø.58 for Valencia (3.2/5.5) and the best at Day Seven was Ø.85 for Adak.

2.2.3.2.5 Average Cloudiness (eighths). The results of this verification are presented in Table 1Ø.

TABLE 1Ø. Average Cloudiness Forecasting Skill.

	MEANS/STANDARD DEVIATIONS (8THS)			
	DAY FIVE		DAY SEVEN	
LOCATION	OBSERVED	ERROR	OBSERVED	ERROR
Kodiak	6.3/2.2	+Ø.4/2.8	6.3/1.6	+1.1/2.Ø
Adak	7.3/Ø.7	-1.Ø/2.3	7.6/Ø.8	-2.1/2.7
Astoria	5.9/1.8	-Ø.3/2.8	6.9/1.1	-Ø.4/3.2
All NE PAC	6.5/1.8	-Ø.2/2.6	6.9/1.3	-Ø.1/2.6
Sable Island	5.7/2.6	-Ø.3/3.5	5.3/2.6	+Ø.4/3.6
Key West	4.3/2.3	-2.6/2.8	3.9/2.2	-1.4/3.1
Hatteras	3.5/3.2	+1.2/3.5	4.3/3.Ø	-1.6/3.8
All NW ATL	4.5/2.9	-Ø.6/3.7	4.5/2.7	-1.1/3.6
Valencia	4.9/2.7	+Ø.6/2.5	5.9/2.6	-Ø.5/3.9
Keflavik	6.9/1.5	-Ø.7/1.9	6.6/1.8	-Ø.4/2.8
La Coruña	5.6/2.8	-2.4/3.8	4.8/3.1	-Ø.6/4.6
All NE ATL	5.8/2.5	-Ø.8/3.1	5.7/2.7	-Ø.5/3.8
TOTAL	5.6/2.6	-Ø.5/3.2	5.8/2.5	-Ø.7/3.4

Assuming a normal distribution of error, about two thirds of the seven-day Kodiak forecasts and more than two thirds of the five-day Keflavik forecasts met the ±2/8 accuracy criteria set forth in Table 1-01 of the Evaluation Plan. The other 16 opportunities were missed. However, even in the two successes cited, a forecast of "average" cloudiness might have been better since the standard deviation (SD) of the observations is less than the SD of the error. The latter general indication of no skill is evident for all but one of the 18 station/forecast-day pairs (the exception being Valencia/day five).

2.2.3.2.6 Lowest Cloud Base. The results of this verification are presented in Table 11.

TABLE 11. Lowest Cloud Base Forecasting Skill.

	MEANS/STANDARD DEVIATIONS (FT x 100)			
	DAY FIVE		DAY SEVEN	
LOCATION	OBSERVED	ERROR	OBSERVED	ERROR
Kodiak	25.1/19.7	-11.3/20.0	28.9/17.8	-16.8/17.9
Adak	12.0/7.8	+2.5/7.1	11.1/6.5	+2.7/7.1
Astoria	23.0/20.3	-7.7/20.1	19.9/16.3	-4.6/15.5
All NE PAC	20.1/17.9	-5.5/17.9	20.0/16.2	-6.2/16.4
Sable Island	25.8/27.4	+12.3/44.4	49.5/31.6	-14.5/43.8
Key West	23.4/19.0	+56.2/22.1	25.9/19.7	+57.3/17.5
Hatteras	63.1/19.8	-22.4/37.4	56.9/23.0	-1.9/34.1
All NW ATL	37.5/28.8	+12.7/48.2	44.1/28.5	+10.7/45.7
Valencia	28.3/19.0	+1.4/25.4	19.9/22.8	+8.2/30.2
Keflavik	18.2/15.2	+8.1/23.4	18.6/18.5	+9.0/29.6
La Coruña	27.6/25.9	+12.3/32.3	30.3/27.4	-3.0/37.0
All NE ATL	24.7/21.0	+7.2/27.5	22.9/23.3	+3.3/33.0
TOTAL	27.4/24.2	4.9/34.0	29.0/25.7	3.6/34.0

Since the maximum "as plotted" value for the height of the base of the lowest cloud is 80 (8,000 feet or more), any forecasts of higher values were converted to 8,000 feet before computing the absolute error. Thus, the maximum possible error is 80 ft x 100. In this verification, as in others above, most scores would have been improved by forecasting the observed mean. In only 4 of the 18 station/forecast-day pairs was the standard deviation of the error (error SD) less than the observed SD, and in all four cases the difference is less than the mean error. No skill at forecasting cloud base is evident.

2.2.3.2.7 Precipitation Expected - yes/no. Table 12 summarizes the results of this verification.

TABLE 12. Precipitation Yes/No Forecasting Skill.

	FORECAST/VERIFICATION COUNTS											
	FIVE DAY FCSTS				SEVEN DAY FCSTS				ALL FORECASTS			
LOCATION	Y/Y	N/N	Y/N	N/Y	Y/Y	N/N	Y/N	N/Y	Y/Y	N/N	Y/N	N/Y
Kodiak	6	---	---	4	5	---	---	2	11	---	---	6
Adak	8	---	---	5	7	1	---	5	15	1	---	10
Astoria	4	2	1	6	4	2	---	6	8	4	1	12
All NE PAC	18	2	1	15	16	3	---	13	34	5	1	28
Sable Island	4	2	---	6	3	2	3	3	7	4	3	9
Key West	---	3	---	---	---	4	---	2	---	7	---	2
Hatteras	1	1	---	2	---	2	---	5	1	3	---	7
All NW ATL	5	6	---	8	3	8	3	10	8	14	3	18
Valencia	8	1	1	2	5	1	2	5	13	2	3	7
Keflavik	10	---	---	2	10	---	---	2	20	---	---	4
La Coruña	4	1	---	6	5	2	---	4	9	3	---	10
All NE ATL	22	2	1	10	20	3	2	11	42	5	3	21
TOTAL	45	10	2	33	39	14	5	34	84	24	7	67

Counts do not equal 16 per station per forecast day because precipitation data were missing from many synoptic reports. Here we see a clear tendency to under-forecast the event (67 total N/Y's versus only 7 Y/N's). This was true for all stations and areas.

Precipitation threat scores (TS) and adjusted threat scores (ATS) are presented in Table 13. (Note, ATS is defined by the footnote to Table 5.)

TABLE 13. Precipitation Forecasting Skill Summary.

	PRECIPITATION FORECASTS					
	5 DAY		7 DAY		BOTH DAYS	
LOCATION	TS	ATS	TS	ATS	TS	ATS
Kodiak	0.60	undef	0.71	undef	0.65	undef
Adak	0.62	undef	0.58	-4.46	0.60	-9.40
Astoria	0.36	-1.77	0.40	-2.60	0.38	-2.10
All NE PAC	0.53	-4.64	0.55	-3.80	0.54	-4.21
Sable Island	0.40	-2.60	0.33	-0.46	0.37	-1.07
Key West	0.00	0.00	0.00	-0.50	0.00	-0.40
Hatteras	0.33	-1.68	0.00	-2.50	0.13	-2.19
All NW ATL	0.38	-0.91	0.19	-0.77	0.28	-0.82
Valencia	0.73	-0.62	0.42	-1.51	0.57	-1.15
Keflavik	0.83	undef	0.83	undef	0.83	undef
La Coruña	0.40	-5.60	0.56	-0.76	0.47	-2.89
All NE ATL	0.67	-2.85	0.61	-1.81	0.64	-2.19
TOTAL	0.56	-2.30	0.50	-1.42	0.53	-1.76

TABLE 13. Precipitation Forecasting Skill Summary (continued).

	NO PRECIPITATION FORECASTS					
	5 DAY		7 DAY		BOTH DAYS	
LOCATION	TS	ATS	TS	ATS	TS	ATS
Kodiak	0.00	0.00	0.00	0.00	0.00	0.00
Adak	0.00	0.00	0.17	0.10	0.10	0.06
Astoria	0.22	-0.01	0.25	0.10	0.24	0.04
All NE PAC	0.11	0.03	0.19	0.10	0.15	0.06
Sable Island	0.25	0.10	0.25	-0.37	0.25	-0.08
Key West	1.00	undef	0.67	0.00	0.78	0.00
Hatteras	0.33	0.11	0.29	0.00	0.30	0.04
All NW ATL	0.43	0.16	0.38	-0.14	0.40	-0.01
Valencia	0.25	0.10	0.13	-0.13	0.17	-0.04
Keflavik	0.00	0.00	0.00	0.00	0.00	0.00
La Coruña	0.14	0.06	0.33	0.19	0.23	0.11
All NE ATL	0.15	0.07	0.19	0.06	0.17	0.07
TOTAL	0.22	0.10	0.26	0.07	0.25	0.09

Both the precipitation threat scores and, because precipitation was so frequent, the no precipitation threat scores are presented. Since ATS=0 approximates random chance, a negative ATS indicates less skill than chance and ATS=1 would be perfect; the precipitation forecasts can be seen to have little to no skill.

<u>2.2.3.2.8 Rain or Shower</u>. Table 14 is the result of this verification. (R/R is rain forecast and rain verified, R/S is rain forecast and shower verified, etc.)

TABLE 14. Rain or Shower Forecasting Skill.

	FORECAST/VERIFICATION COUNTS											
	FIVE DAY FCSTS				SEVEN DAY FCSTS				ALL FORECASTS			
LOCATION	R/R	S/S	R/S	S/R	R/R	S/S	R/S	S/R	R/R	S/S	R/S	S/R
Kodiak	1	3	2	---	1	4	---	---	2	7	2	---
Adak	3	4	---	1	3	1	---	3	6	5	---	4
Astoria	1	2	1	---	---	3	1	---	1	5	2	---
All NE PAC	5	9	3	1	4	8	1	3	9	17	4	4
Sable Island	1	2	---	1	1	1	---	1	2	3	---	2
Key West	---	---	---	---	---	---	---	---	---	---	---	---
Hatteras	---	1	---	---	---	---	---	---	---	1	---	---
All NW ATL	1	3	---	1	1	1	---	1	2	4	---	2
Valencia	1	3	3	1	3	1	---	1	4	4	3	2
Keflavik	5	---	2	3	5	3	1	1	10	3	3	4
La Coruña	1	2	1	---	---	3	---	2	1	5	1	2
All NE ATL	7	5	6	4	8	7	1	4	15	12	7	8
TOTAL	13	17	9	6	13	16	2	8	26	33	11	14

The counts in this verification are low because each requires both the forecast and the reported occurrence of precipitation. Also, a computed "precipitation average amount" (PTA) as specified in the Evaluation Plan's scoring rules proved unreliable. Instead a count of reported present weather showers (ww greater than 79) and reported past weather showers (W greater than 7) was made. Half or more of the maximum possible count resulted in a correct (R/R or S/S) forecast.

Ability to distinguish between predominately intermittent and predominately steady precipitation appears very good. Seventy percent of all verifiable forecasts were correct and only one area/Tau set was less than 65% correct (NE ATL, T120 was

55%). Surprisingly more seven-day forecasts were correct than five-day forecasts (75% versus 67%) but the sets are small and the difference is probably not significant.

2.2.3.2.9 Frozen Precipitation - yes/no. The results of this verification are presented in Table 15.

TABLE 15. Frozen Precipitation Forecasting Skill.

	FORECAST/VERIFICATION COUNTS											
	FIVE DAY FCSTS				SEVEN DAY FCSTS				ALL FORECASTS			
LOCATION	Y/Y	N/N	Y/N	N/Y	Y/Y	N/N	Y/N	N/Y	Y/Y	N/N	Y/N	N/Y
Kodiak	---	6	---	---	1	3	1	---	1	9	1	---
Adak	---	7	1	---	---	7	---	---	---	14	1	---
Astoria	---	4	---	---	---	4	---	---	---	8	---	---
All NE PAC	---	17	1	---	1	14	1	---	1	31	2	---
Sable Island	---	4	---	---	---	3	---	---	---	7	---	---
Key West	---	---	---	---	---	---	---	---	---	---	---	---
Hatteras	---	1	---	---	---	---	---	---	---	1	---	---
All NW ATL	---	5	---	---	---	3	---	---	---	8	---	---
Valencia	---	6	---	---	---	5	---	---	---	11	---	---
Keflavik	1	9	---	---	---	8	---	1	1	17	---	1
La Coruña	---	4	---	---	---	5	---	---	---	9	---	---
All NE ATL	1	19	---	---	---	18	---	1	1	37	---	1
TOTAL	1	41	1	---	1	35	1	1	2	76	2	1

The counts in this verification are low because each requires both the forecast and the reported occurrence of precipitation. A minor modification to the Evaluation Plan's scoring rules was the addition of WW codes 22, 23 and 26 as frozen indicators.

As with 25 knot winds, skill assessment is impossible because the occurrence of the event at the station was so infrequent during the forecasting period. A winter hemisphere evaluation is required.

2.2.3.2.10 Surface Visibility <3 Mi - yes/no. The results of this verification are presented in Table 16.

TABLE 16. Visibility <3 Miles Forecasting Skill.

	FORECAST/VERIFICATION COUNTS											
	FIVE DAY FCSTS				SEVEN DAY FCSTS				ALL FORECASTS			
LOCATION	Y/Y	N/N	Y/N	N/Y	Y/Y	N/N	Y/N	N/Y	Y/Y	N/N	Y/N	N/Y
Kodiak	---	16	---	---	---	16	---	---	---	32	---	---
Adak	---	15	---	---	---	15	---	---	---	30	---	---
Astoria	---	15	---	---	---	15	---	1	---	30	---	1
All NE PAC	---	46	---	---	---	46	---	1	---	92	---	1
Sable Island	---	9	3	4	2	7	3	3	2	16	6	7
Key West	---	14	---	---	---	15	---	---	---	29	---	---
Hatteras	---	12	2	---	---	14	---	---	---	26	2	---
All NW ATL	---	35	5	4	2	36	3	3	2	71	8	7
Valencia	---	15	1	---	---	14	1	1	---	29	2	1
Keflavik	1	12	1	2	---	13	---	3	1	25	1	5
La Coruña	---	15	---	1	---	15	---	1	---	30	---	2
All NE ATL	1	42	2	3	---	42	1	5	1	84	3	8
TOTAL	1	123	7	7	2	124	4	9	3	247	11	16

Again, the occurrence of the event was too rare for meaningful skill assessment.

2.2.3.3 Intertropical Covergence Zone (ITCZ) Location. As indicated in the Evaluation Plan, the TAU 120 and 168 wind fields

at 1000 and 850 mb plotted as wind barbs were to be used to forecast the development or movement of the ITCZ. Satellite imagery (both visual and IR) was to be used for verification.

During a one week warm-up and for the first forecast the slightest confluence in the forecast winds was used to forecast the formation of an ITCZ. However, when verification did not support these forecasts, a more conservative evaluation of the forecast fields was used for the remaining 6-7 weeks of the evaluation period. Though the ITCZ forecaster "knew from experience" that the ITCZ should form very soon, he nevertheless followed the NOGAPS forecast field guidance which, with conservative evaluation, never indicated the formation of an ITCZ in either hemisphere. Based upon the available satellite data, these no-ITCZ forecasts were all correct. The NEPRF Contract Monitor was informed after a few weeks of the persistent lack of any verifiable ITCZ. It was decided to continue forecasting, however, since it was reasonable to expect the formation of a convergence zone sometime during the remainder of the evaluation period.

The wind shear lines penetrating into the tropics from the poleward regions were well reflected in both the analysis and forecast fields. The observed cloudiness around low pressure systems was also well depicted by the convergence in both the analysis and forecast fields. But, from the forecast fields it was also apparent that no ITCZ would form and, as previously stated, none did form during the entire eight-week period. Therefore, whether the forecast (or analysis) wind field would properly portray a developing or existing ITCZ could not be determined during this evaluation.

The satellite imagery used for verification was the DMSP (as processed by FNOC) and the "Japanese GOES" as received by FNOC. Verification of the analyses and forecasts were easier with the Japanese satellite data; but, since it was common for at least

one "panel" of a composite GOES image to be missing for each time of receipt, the DMSP data were also required for verification.

2.2.3.4 Sensible Weather Forecasting Results Summary. Of the 11 sensible weather forecast parameters (including the ITCZ), skill was shown only in one (rain or shower). Four were inconclusive due to insufficient events at the stations during the evaluation period (wind $\geq$ 25 kt, frozen precipitation, visibility restriction and ITCZ location). No skill was demonstrated in forecasting the remaining six parameters - surface wind speed, surface wind direction, surface air temperature, average cloudiness, lowest cloud base and precipitation expected.

2.2.3.5 Forecaster Comment Summary. The second page of the forecaster questionnaire (Figure 2-12) was filled out following the eight-week forecasting period. Comments received were highly diverse, but opinions shared by at least two of the four forecasters follow.

Particularly Useful NOGAPS Products: 500 mb heights, surface pressure and air temperature and 1000 mb winds for station forecasting; 1000 mb and 850 mb winds for ITCZ forecasting. Reasons were generally not provided.

Least Useful NOGAPS Products: PBL depth, stratus thickness and stratus frequency; because of unfamiliarity and difficulty reading the plots.

Recommended Product Changes or Additions: No consensus at all.

Recommended Procedural Changes: Make some sort of running (or recent) score (or model skill) assessment (statistics or display) available to the forecasters.

MRFE FORECASTER QUESTIONAIRE (continued)

NAME: ______________________________________ DATE: _________

WHAT NOGAPS PRODUCTS WHERE PARTICULARLY USEFUL AS GUIDANCE AND WHY? ____

____

____

____

____

WHAT NOGAPS PRODUCTS WERE NOT USEFUL AS GUIDANCE AND WHY? _______

____

____

____

____

WHAT PRODUCT CHANGES OR ADDITIONS DO YOU RECOMMEND FOR FUTURE EVALUATIONS? ____

____

____

____

____

WHAT PROCEDURAL CHANGES DO YOU RECOMMEND FOR FUTURE EVALUATIONS?

____

____

____

____

____

FIGURE 2-12. Second page of the Medium-Range Forecast Evaluation (MRFE) Forecaster Questionnaire.

2.2.4 Systematic Error Identification System (SEIS).

2.2.4.1 Evaluation Procedure. As described in more detail in the Evaluation Plan, SEIS tracks up to 5 low pressure centers and correlates analyzed center positions, shapes and intensities with forecast centers. Errors related to the forecast track and center amplitude are calculated. For this evaluation, the operational application of SEIS over the North Pacific at FNOC for TAU's 00 through 60 was modified and extended to permit calculation of TAU 72-168 errors over the same North Pacific area (see Figure 2-02). Only 00 GMT forecast runs were evaluated since longer-range forecasts were not prepared based on the 12 GMT observed data. Intermediate 12 hourly analyzed track continuity was maintained, however.

SEIS data collection for this evaluation began on 10 April and continued through 15 June, but because of several problems only 30 SEIS Vortex Tracking runs were successfully completed through TAU 168. Because the three days of data collected on 12, 14 and 15 June was separated from earlier data by two weeks and therefore lacked track continuity, it was decided to reduce only that data collected between 10 April and 28 May.

Statistical summaries were produced with newly revised NEPRF software which did not yet include track error and timing error calculations. These are therefore not included in the results, but some related qualitative conclusions are reached using latitudinal and longitudinal error statistics.

2.2.4.2 Results. NOGAPS success in forecasting the life cycle (not the precise track) of 27 individual North Pacific storms tracked by SEIS during the 49-day period is summarized in Table 17.

TABLE 17. SEIS Tracking Summary.

	TAUs							
	00	24	48	72	96	120	144	168
Nr. of low pressure centers analyzed (TAU 00) or forecast:	112	92	100	87	75	60	60	68
Nr. of centers matched and verified by SEIS at indicated TAU:	---	59	43	30	24	17	11	9
Nr. of centers matched and verified at some other TAU:	---	17	29	29	28	21	23	20
Nr. of centers never matched by SEIS:	---	16	28	28	23	22	26	39

The top line of the table shows that 112 low pressure centers were identified and tracked by SEIS, 87 substantial storms (by SEIS selection criteria) were forecast by the prediction model to exist at TAU 72 and 68 were predicted for TAU 168 (day 7 of a forecast cycle). Since there were 27 storms tracked and 112 centers analyzed, the average storms life was approximately four days. The general decrease in the number of low centers with increasing TAU probably reflects a loss of ability to forecast the shorter waves. The unexplained increase to 68 at T168 would be significant if it was caused by increased noise in the model.

The second line shows, however, that only 30 of the 87 three-day forecast centers verified on that day and only 9 of the 68 seven-day forecast centers were actually verified by SEIS. That is not to say that the other 59 seven day forecast centers

did not exist, perhaps very near their forecast position, but they did not have SEIS track continuity to this point.

Line three shows the large number of forecast centers which verified at one or more other TAU's but which were not verifiable by SEIS at the indicated TAU. In most cases the actual low will have weakened below the SEIS tracking threshold at an earlier TAU. If the low subsequently reintensified SEIS would consider that a case of cyclogenesis, the center would be given a new identifier, and SEIS would look for a center match with a new forecast low (not with an older continuously tracking forecast low). In 5 of the 27 cases the low was predicted by NOGAPS to form earlier than it was actually picked up on the analysis by SEIS, but in 22 cases (not necessarily the other 22 cases) the SEIS-tracked lows were predicted to retain their identify longer than observed. Cyclogenesis was forecast in advance in only 8 of the 27 cases and never consistently in a series more than 2 days in advance. Line four centers are clear false alarms - those cases where SEIS never matched a forecast center track with an analyzed center track. Of 87 centers forecast to exist at TAU 72, 28 (32%) never formed or at least never formed where they could be correlated with an analyzed storm track. At TAU 168 this percentage increases to 57.

Table 18 provides error statistics (forecast minus analysis) for those forecast surface lows which were successfully matched with analyzed lows and verified by SEIS (those identified in line 2 of Table 17).

TABLE 18. SEIS Error Summary.

		TAUs						
		24	48	72	96	120	144	168
Pressure (mb):	Avg Error	-1.7	-3.7	-2.5	-3.7	-4.9	1.5	2.1
	STD of Error	4.32	6.59	7.67	9.51	11.35	11.87	9.29
Latitude (deg):	Avg Error	0.0	-1.2	-1.6	-0.8	0.5	0.4	2.0
	STD of Error	2.35	2.69	4.22	3.65	3.46	3.35	3.67
Longitude (deg):	Avg Error	-0.5	0.3	-0.7	-1.6	-1.2	-2.9	-3.0
	STD of Error	5.41	4.66	7.03	6.49	6.82	9.36	12.38
Distance (nm):	Avg Error	177	214	316	304	285	350	477
	STD of Error	180	128	204	142	153	212	203
Nr. of Cases:		59	43	30	24	17	11	9

There is an abrupt shift between TAU's 120 and 144 from forecasting too much amplitude (pressure centers too low) to their being too high in central pressure. Distance errors increase markedly as would be expected at the higher TAU's and are increasingly biased toward the east (Note: the longitude convention is 0-360 westward) and shift from south of track at lower TAU's to north of track at higher TAU's. The model is obviously fast in movement and to the right of the actual track.

SECTION 3. SUMMARY CONCLUSIONS AND RECOMMENDATIONS

3.1 Procedures. Except for the problems when using magnetic tape for data scores, the procedures required to implement the Medium-Range Forecast System Evaluation Plan worked very well and are repeatable by NEPRF. A detailed description of the magnetic tape problems are delineated in SASC, 1984. All job streams and corrected software developed during this contract have been delivered to the Contract Monitor. All suggested changes to these procedures are contained in subsection 3.4 of this report.

3.2 Accuracy Assessment. In this subsection several key measures of forecast system skill are displayed in measure value versus TAU graphic summary form.

Figure 3-01 (bottom) shows the anomaly correlation (AC) scores at the four levels for the four TAUs. The European Centre for Medium Range Weather Forecasts (ECMWF) has concluded that an AC score must be at least .50 to be useful. If such a criteria is reasonable for Navy applications, one sees little skill past T96 at 1000 mb, little past T120 at 850 mb and little past T144 at the two highest levels.

Figure 3-01 (top) shows the considerable greater skill in the lower wave numbers (WN) at 500 mb over the Northern Hemisphere and also how the difference between WN 1-3 and WN 4-9 increases dramatically at the higher TAUs.

Figure 3-02 illustrates the difference in skill from area to area at 500 mb (top) and at 1000 mb (bottom). The ocean areas show more skill than the hemispheres at 1000 mb, but this does not hold true at 500 mb in the Northern Hemisphere.

In Figure 3-03 we see the month-to-month variation between areas. This is particularly marked in the South HEMI which shows much more skill in April than in May.

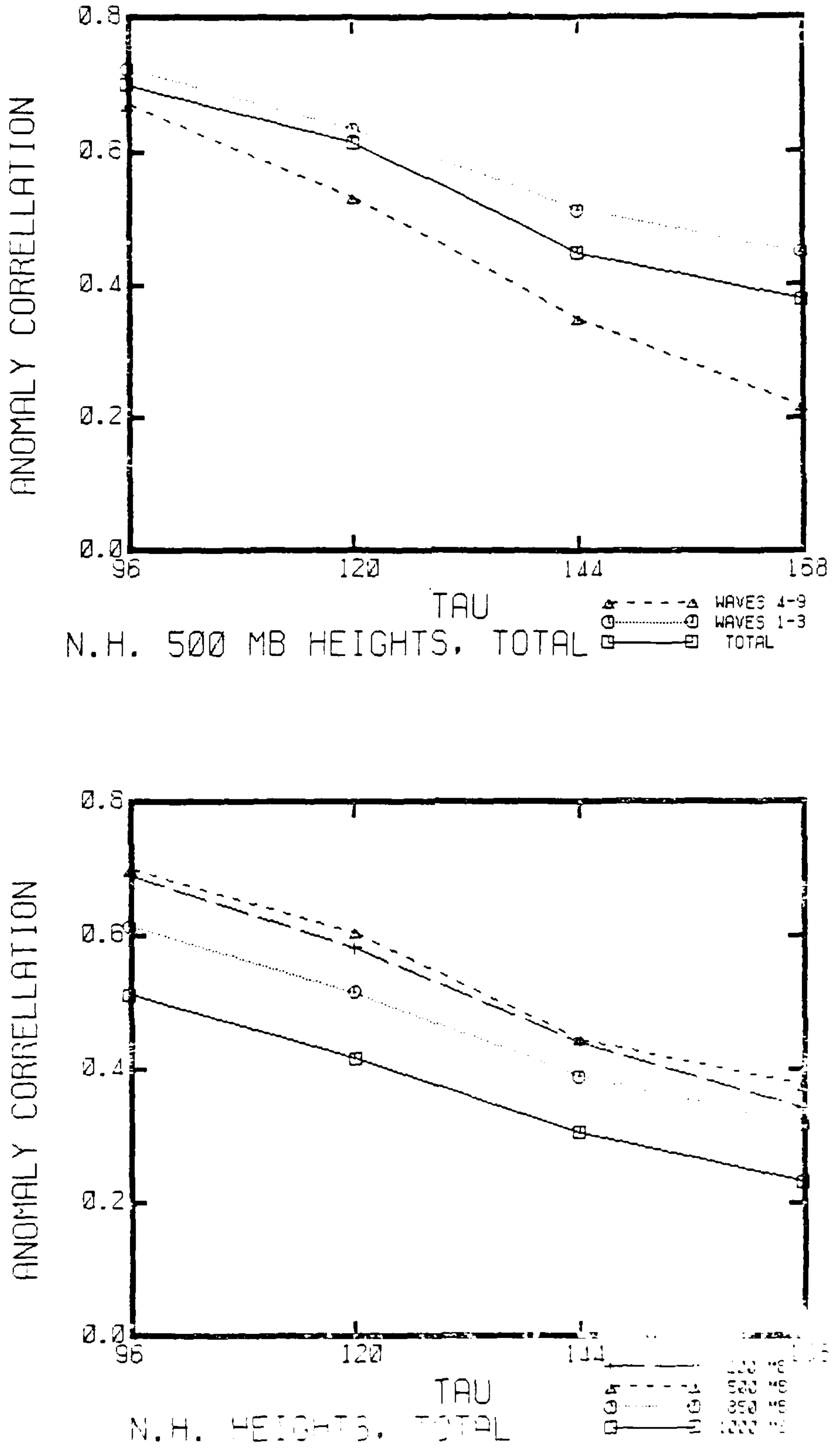


FIGURE 3-11. North HEMI Anomaly Correlations of Height (level and wave number comparisons).

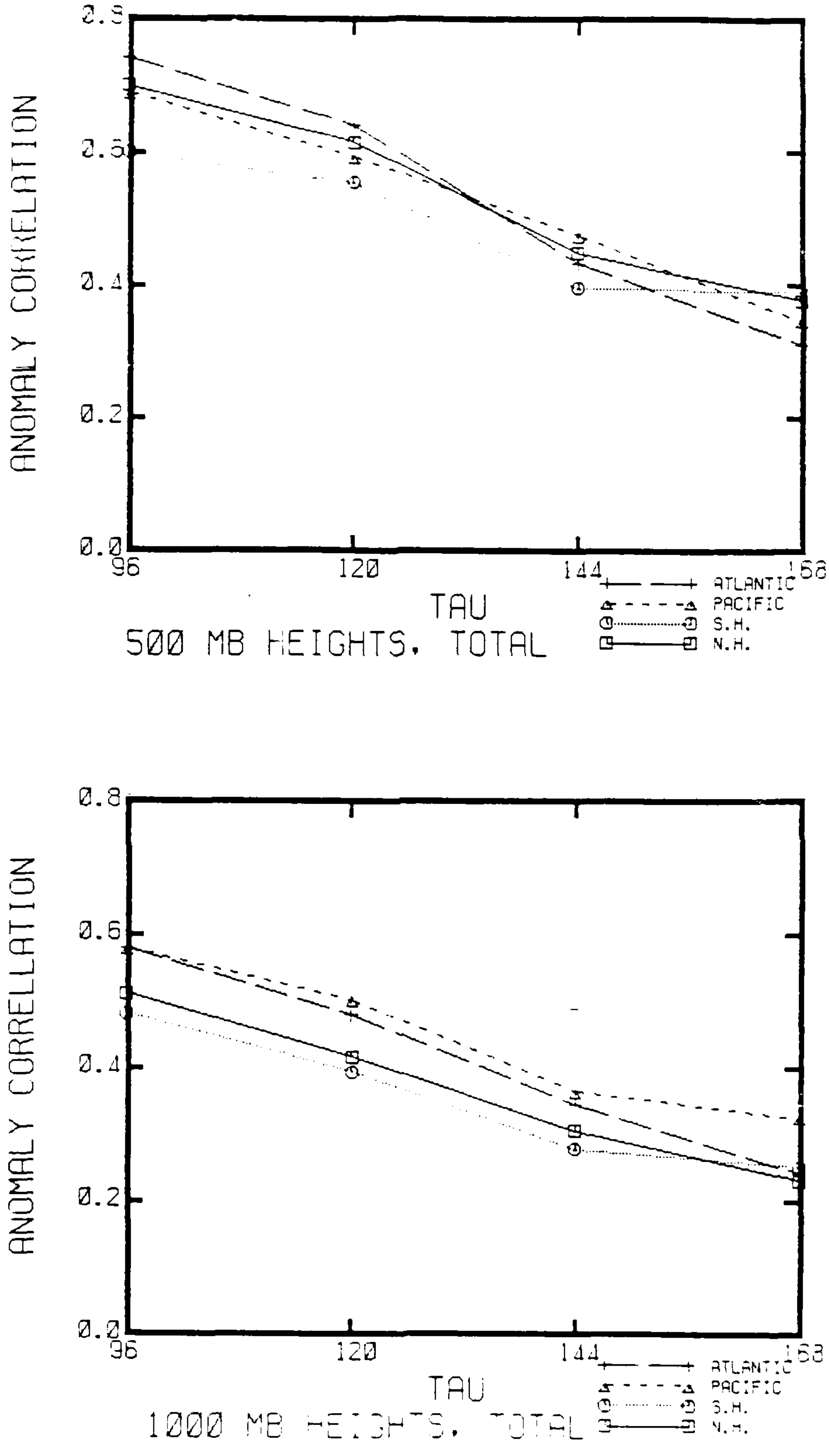


FIGURE 3-02. North HEMI Anomaly Correlations of Height (level and area comparisons).

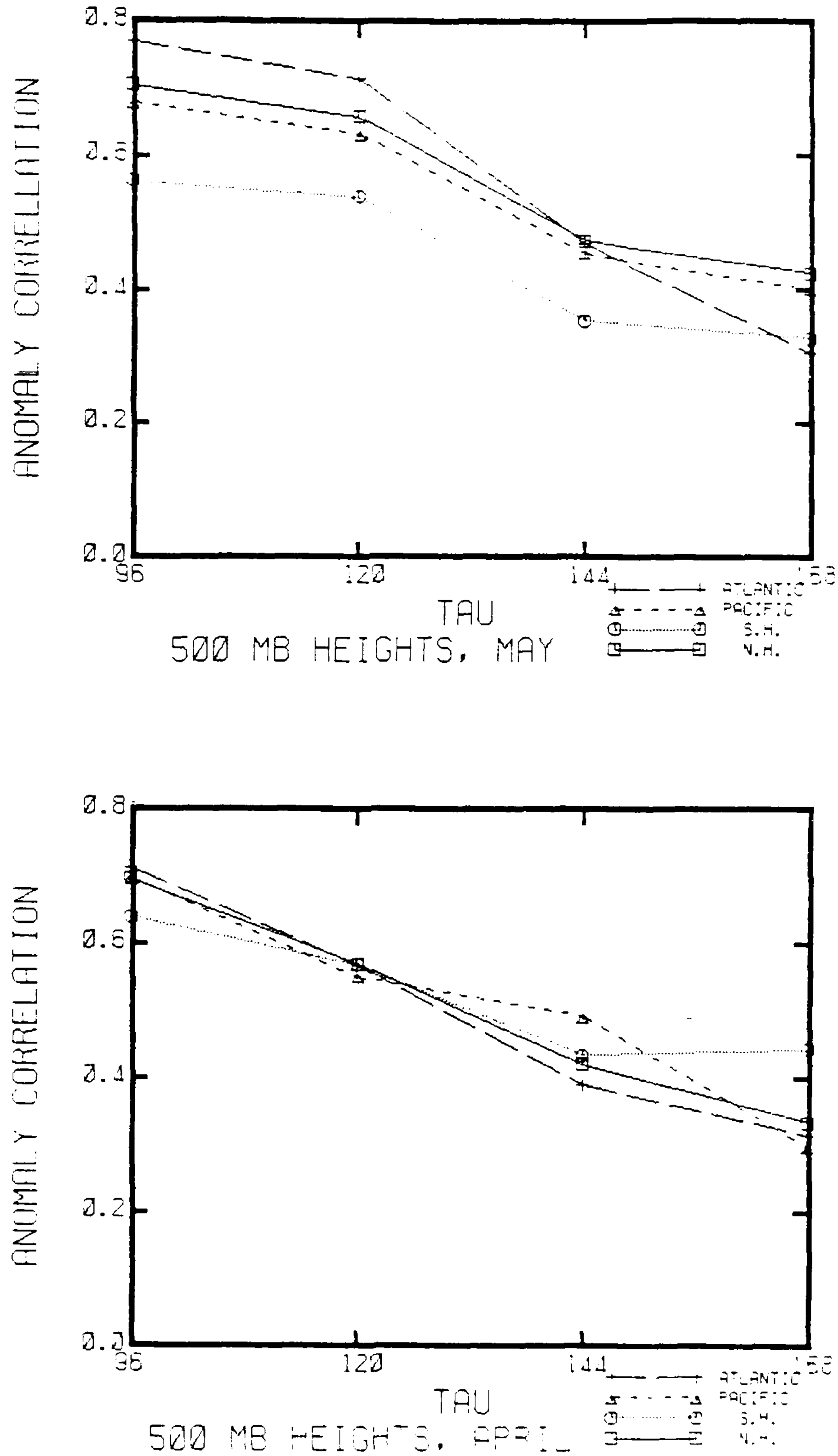


FIGURE 3-33. Anomaly Correlations of Height (area and month comparisons).

The AC scores for temperature are shown in Figure 3-Ø4. Unlike the heights (Figure 3-Ø1 (bottom)), the temperatures show greater skill at the lower levels, particularly at the longer TAUs.

RMS errors of wind are depicted in Figure 3-Ø5. The scalar errors (top) increase only slightly as TAU increases and are generally proportional to the mean wind at the four levels. The directional errors (bottom) also increase slightly with increasing TAU, but are about 2Ø degrees larger at the lower two levels.

Figure 3-Ø6 compares the two month combined Northern Hemispheric mean height errors at the four levels (top) with the mean temperature errors (bottom). The same information for the Southern Hemisphere is shown in Figure 3-Ø7. Note the warming with time at 2ØØ mb in both hemispheres and the corresponding large positive height errors - particularly in the Southern Hemisphere. This same warming tendency is also noticeable at 5ØØ mb in the Southern Hemisphere. Cooling is noted at the lower levels in both hemispheres.

<u>3.3 Utility Assessment</u>. The Evaluation Plan stated that the forecast system's usefulness - its ability to meet the needs of operational forecasters - would be assessed. Such an assessment, however, becomes difficult and potentially misleading when the data collection phase is as short as this one was and the number of significant phenomenological events are so limited. In the interest of providing an outline for future evaluations, a minimal assessment is provided below; but the reader is cautioned to not make any value judgments from what follows. A true utility assessment should consider the recommendations made in subsection 3.4 and will certainly require a longer period of data collection.

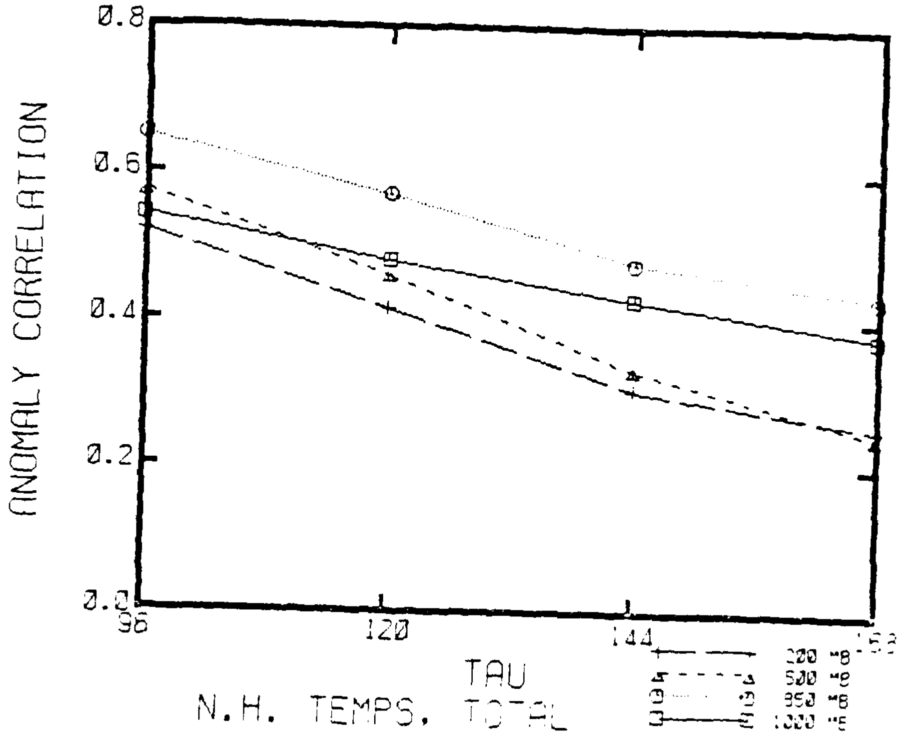
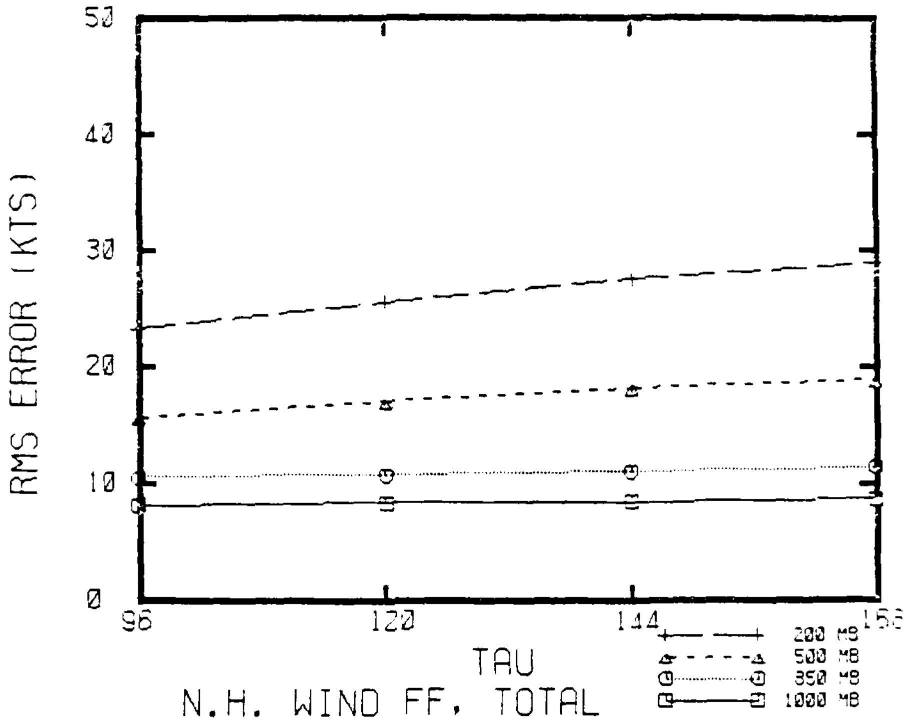


FIGURE 3-04. North HEMI Anomaly Correlations
of Temperature (level comparisons).



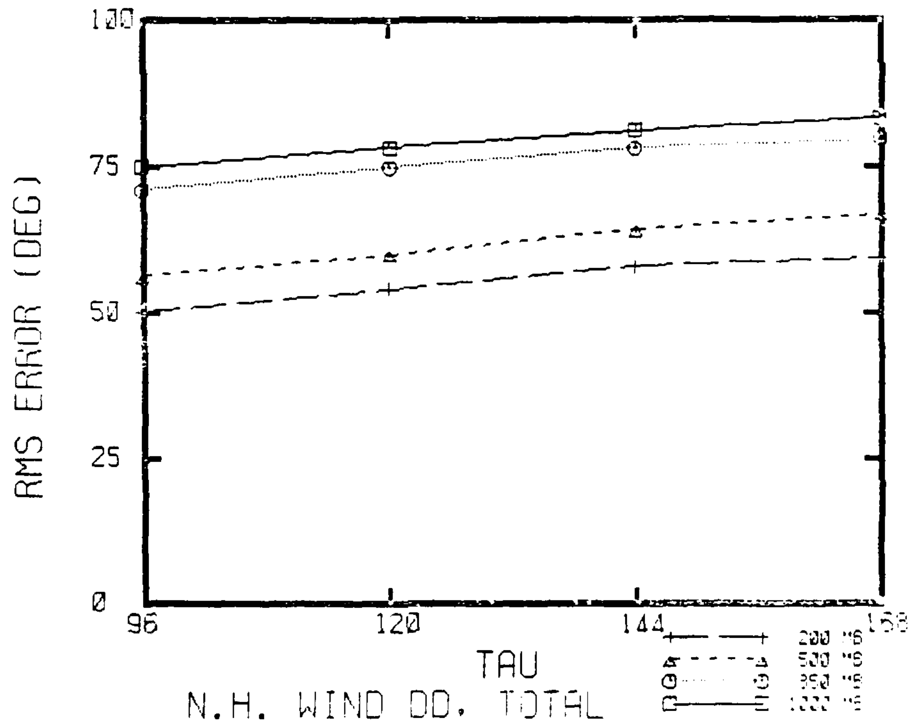


FIGURE 3-05. North HEMI RMS Wind (DD and FF) Errors (level comparisons).

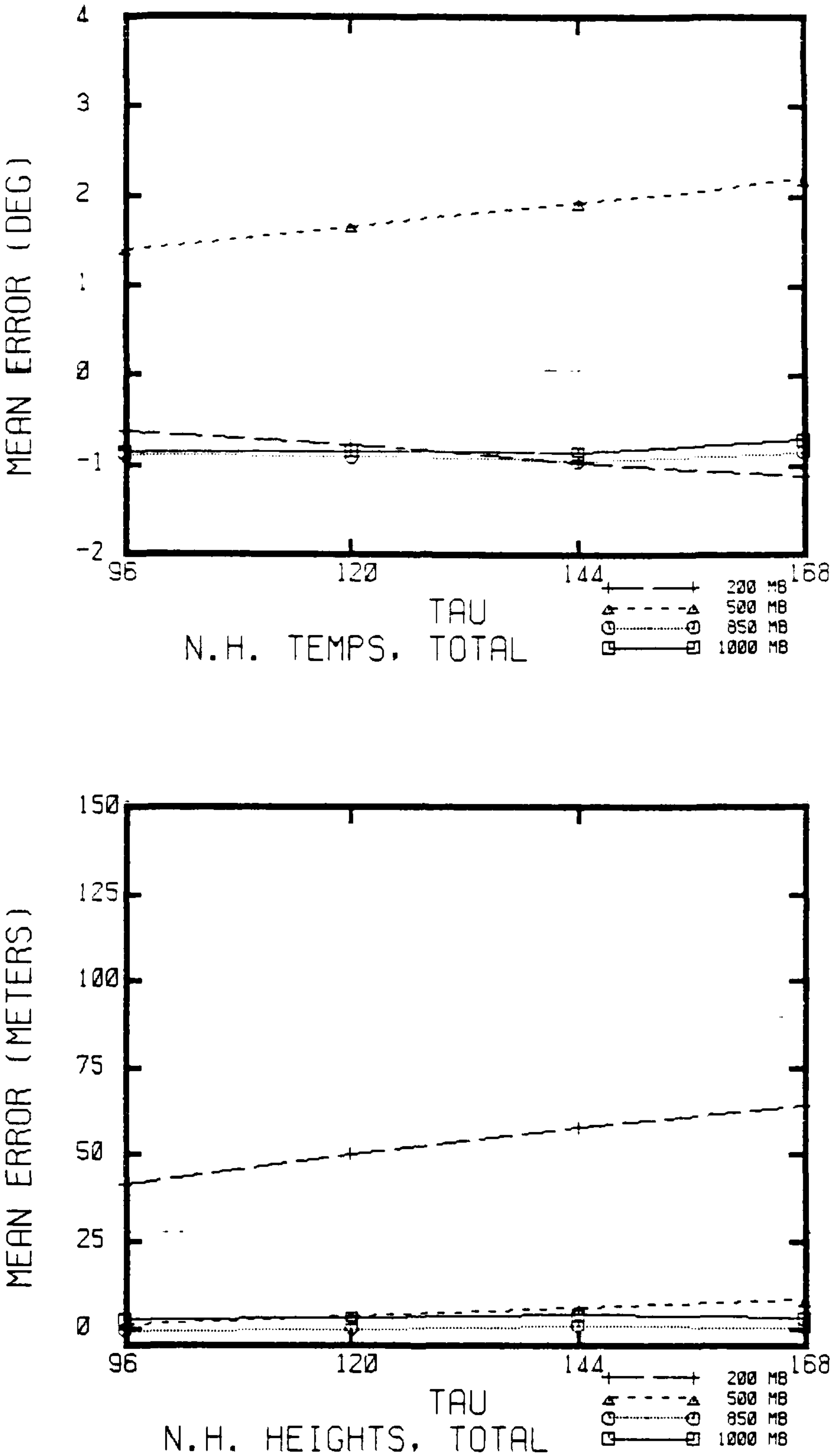


FIGURE 3-06. North HEMI Mean Height and Temperature Errors (level comparisons).

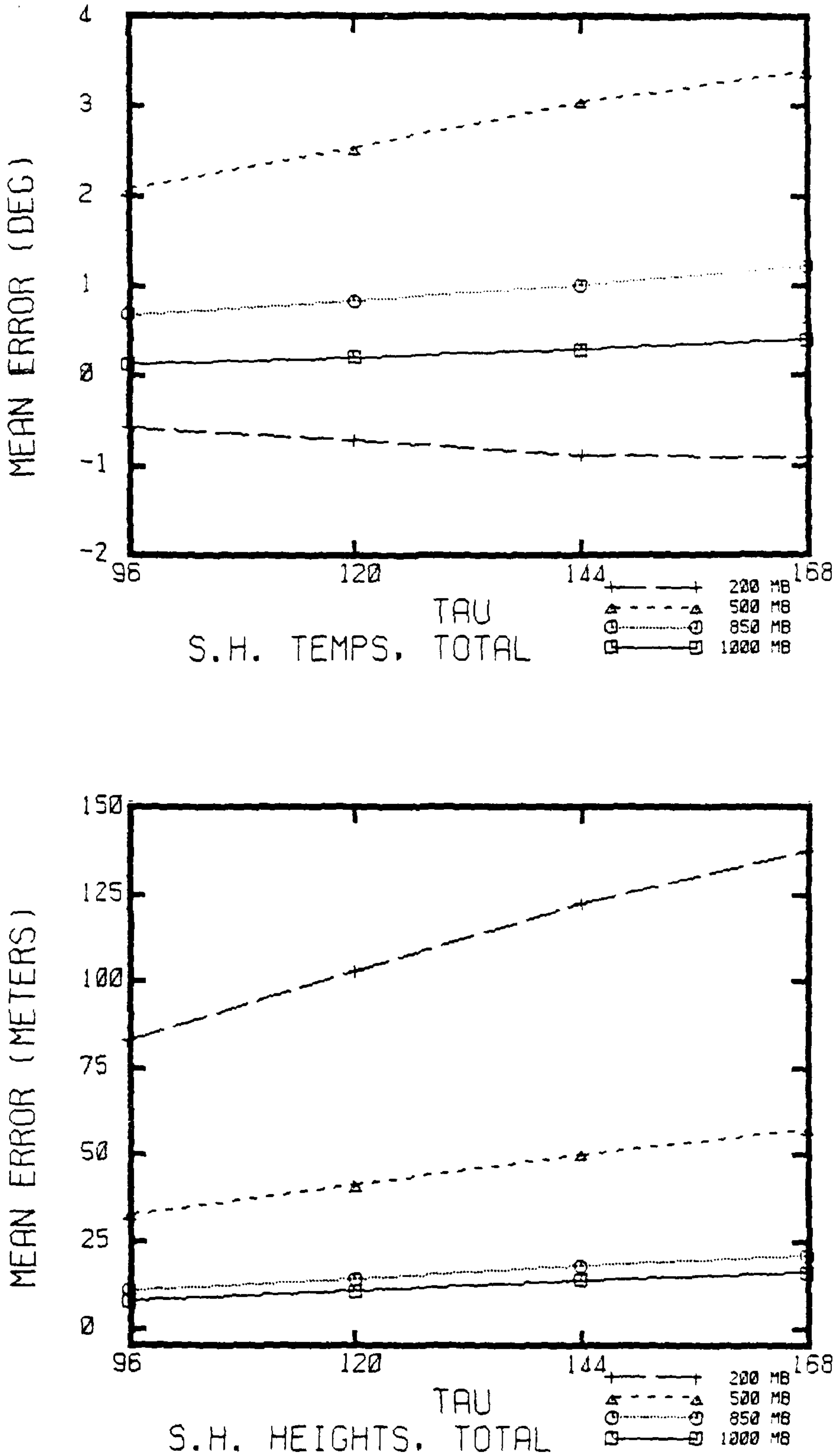


FIGURE 3-07. South HEMI Mean Height and Temperature Errors (level comparisons).

Certain accuracy criteria were set forth in Elsberry et al (1984) and are reproduced here as Figure 3-08. These criteria provide a potential measure of usefulness. In discussing them below we will consider only the day five results, since the evaluation forecasts extended no further than day seven.

<u>Extratropical Storm Track</u>: Referring to the tables in subsection 2.2.4.2, latitudinal error of less than 1.0 deg (60 nm) should approximate the average track error for eastward moving storms and the latitudinal error of less than 1.5 deg (90 nm) should approximate the track error for northward moving storms. Since both are well within the 200 nm criteria of Figure 3-01, these results are encouraging as is a latitudinal SD of only 3.46 deg (208 nm). Less encouraging is the longitudinal SD of 6.82 deg (409 nm). And of course these figures do not include any errors for the 22 centers forecast to exist at TAU 120 but never matched by SEIS.

<u>Surface Wind Speed</u>: Based on the sensible weather forecasting results (subsection 2.2.3.2.2), the 5.6 kt error SD is far more than 25 percent of the observed 9.0 kt average. Observed 1000 mb values are not available in the Appendix, but RMS errors at 1000 mb of 8-10 kt must surely be more than 25% of the actual April-May mean low level wind speed.

<u>Surface Wind Direction</u>: Sensible weather forecasters were able to predict day-five wind directions within 45 deg only 30% of the time. This is not surprising since RMS directional errors at 1000 mb were all in excess of 70 deg.

<u>Free Atmospheric Wind Speed</u>: Without observed mean values, it is impossible to determine if the 20 percent criteria was met.

<u>Free Atmospheric Wind Direction</u>: RMS wind direction errors approach 45 deg at 200 mb in the S. HEMI (47 deg at T120) but at all other levels and in all other areas they are higher; as much

WEATHER PARAMETER	ACCURACY AT FIVE DAYS	ACCURACY AT TEN DAYS
Extratropical Storm Track	200 nm avg. STE[1]	400 nm avg. STE[1]
Wind		
Sfc[2] speed	± 25%	± 50%
Sfc[2] direction	± 45 degrees	± 60 degrees
FA[3] speed	± 20%	± 40%
FA[3] direction	± 45 degrees	± 60 degrees
Temperature		
Sfc[2]	± SStdDev[4] • 0.4	± SStdDev[4] • 0.7
FA[3]	± 5°C	± 10°C
Clouds		
cover	± 25% (± 2/8)	clear or scattered/ broken or overcast
dominant type	cumuliform/mixed/ stratiform	cumuliform/mixed/ stratiform
base of dominant	low/middle/high	low/high
Precipitation	likely/possible/unlikely	likely/unlikely
amount (if likely/possible)	light/moderate/heavy	light/heavy
type (if likely/possible)	steady/mixed/showers	PNP[5]
frozen (if likely/possible)	yes/possible/no	likely/unlikely
Visibility	<3/3-6/>6 mi	PNP[5]
Waves (sea, swell & surf)	(sfc wind & geography dependent)	(sfc wind & geography dependent)

NOTES:

[1]STE is Surface Track Error; the minimum distance between forecast cyclone positions at prime synoptic times and the verifying cyclone track.

[2]Sfc is surface value at about two meters altitude.

[3]FA is free atmosphere above the planetary boundary layer.

[4]SStdDev is the Seasonal Standard Deviation.

[5]PNP means probably not predictable.

FIGURE 3-08. Acceptable Levels of Accuracy.

as 91 deg at 850 mb in the tropics.

Surface Temperatures: Based on sensible weather forecasting results (subsection 2.2.3.2.4), the 5.8 deg error SD is 60 percent of the 9.8 observed SD (far more than the 40 percent criteria). Observed 1000 mb temperature values are not available from the field verifications.

Free Atmosphere Temperatures: RMS temperature errors at day five, T120 are all very close to 5 deg - somewhat less at 850 and 500 mb, very slightly more at 200 mb.

Cloud Cover: Based on sensible weather forecasting results (subsection 2.2.3.2.5), an error SD of 3.2 eighths is over 50% of observed 5.6 eighths mean and even greater than the 2.6 eighths SD of the observations.

Cloud Type (dominant): There was no attempt to verify the models ability to forecast types of clouds.

Cloud Base (dominant): Based on sensible weather forecasting results (subsection 2.2.3.2.6), the error SD of 3400 ft was greater than both the observed mean and the observed SD and was 43 percent of the maximum possible range (0-8000 ft).

Precipitation Expected: Based on sensible weather forecasting results (subsection 2.2.3.2.7), the models guidance value for precipitation-yes-or-no predictions was negligible.

Precipitation Amount: There was no attempt to verify the models ability to forecast amount of precipitation.

Precipitation Type: Based on sensible weather forecasting results (subsection 2.2.3.2.8), the ability to distinguish between rain and showers (when they occurred) was good - 70 percent of such verifiable forecasts were correct.

Precipitation Frozen: There were insufficient frozen precipitation events observed or forecast during this evaluation.

Visibility Restriction: There were insufficient observations or forecasts of restricted visibility during this evaluation.

3.4 Recommendations for Future Evaluations. In this subsection changes which would improve similar future evaluations are listed in the same general order as the findings were presented in Section 2. But first two general recommendations:

- Conduct the evaluation over a longer period which, as a minimum, would include a complete winter season. This would provide sufficient gales, mature storms and other adverse weather events to permit meaningful gale warning, SEIS and sensible weather forecasting evaluations.

- Prohibit major forecast model changes during the course of the evaluation. But, if such changes are required, the expected ramifications should be carefully documented at the time they are made so that effects can be monitored by and accounted for in the evaluation.

- Review the acceptable levels of accuracy set forth in the Evaluation Plan (Figure 3-08 herein) and restate in more easily interpreted and measurable terms. For example: In the plan acceptable five day temperature accuracy is specified as seasonal standard deviation times 0.4. This could be more precisely stated as "standard deviation of the error $\leq$ seasonal observed standard deviation x 0.4". Similar measures should be considered for wind speed and cloud cover. Also, acceptable storm track accuracy would be better expressed in terms of standard deviation of the error rather than average error.

3.4.1 Field Verification Recommendations.

- Calculate observed (TAU 00) means and standard deviations and make these available for inclusion in an appendix and for analytical purposes.

- Eliminate calculating the standard deviation of the verifying anomaly since these statistics have no apparent value in the assessment of medium-range forecasting skill.

- Eliminate the common longitude boundary at 180 in the Pacific and at 35W in the Atlantic. This would preclude overlap which causes the same data to enter separate subarea statistics.

3.4.2 Special Verifications.

- Add track error and timing error calculations to the new SEIS statistical package.

- Establish another mean storm track regional grid over the North Atlantic and/or other area(s) of Navy interest so that skill can be compared between regions.

- Distribute mean storm track plots to several operational meteorologists for their evaluation as forecasting guidance. Their opinions as to the relative day-to-day worth of the plots should also be solicited and used to determine a threshold of usefulness for correlation coefficients.

- Eliminate the overly-involved 30-36 kt gale warning scoring criteria, but retain the percent scores for grid-point count differences, thus providing a measure of to what degree gales are under- or over-forecast.

- Adjust the number and location of gale warning areas as operational interest may indicate.

- Forecast and score sensible weather wind direction by tens of degrees, as reported, rather than by quadrants or octants. This would be easier to score and more precise.

- Involve currently active Navy forecasters - at Ocean Centers and/or Detachments - in sensible weather forecasting.

- Discontinue or else redraft the sensible weather forecasters questionnaire in more precise yes/no, multiple choice terms.

- Provide sensible weather forecasters some skill feed-back such as their raw scores and/or field verification scores for their forecasting areas/points during the course of the evaluation.

REFERENCES

Elsberry, R. L., H. D. Hamilton, and P. A. Petit, 1984: Accuracy and Operational Use of Medium and Extended-Range Numerical Atmospheric Forecasts: A Review. NAVENVPREDRSCHFAC Contract Report (number not yet assigned). Systems and Applied Sciences Corporation, 570 Casnova Avenue, Monterey, California, 82 pp.

Petit, P. A., H. D. Hamilton, and R. L. Elsberry, 1984: A Medium-Range Atmospheric Forecast System Evaluation Plan. NAVENVPREDRSCHFAC Contract Report (number not yet assigned). Systems and Applied Sciences Corporation, 570 Casanova Avenue, Monterey, California, 33 pp.

SASC (Systems and Applied Sciences Corporation), 1984: Medium Range Forecast Evaluation FINAL REPORT FOR TASK III. NSC Contract No. N00228-83-C-3101. Systems and Applied Sciences Corporation, 570 Casanova Avenue, Monterey, California, 9 pp.

KEY TO ABBREVIATIONS

AC	anomaly correlation
ATL	Atlantic Ocean
FNOC	Fleet Numerical Oceanography Center
HEMI	Hemisphere (north or south)
mb	millibar (unit of atmospheric pressure)
MRFE	Medium-Range Forecast Evaluation
NEPRF	Naval Environmental Prediction Research Facility
NOGAPS	Navy Operational Global Atmospheric Prediction System
PAC	Pacific Ocean
RMS	root-mean-square (error)
SD	standard deviation
SEIS	Systematic Error Identification System
T	Same as TAU (see below)
TAU	Term used with a numeric modifier to indicate length of forecast in hours
TROP	Tropics

DISTRIBUTION

COMMANDING OFFICER
NORDA
NSTL, MS 39529

COMMANDING OFFICER
FLENUMOCEANCEN
MONTEREY, CA 93943-5105

COMMANDING OFFICER
NAVWESTOCEANCEN
BOX 113
PEARL HARBOR, HI 96860

COMMANDING OFFICER
NAVEASTOCEANCEN
MCADIE BLDG. (U-117)
NAVAL AIR STATION
NORFOLK, VA 23511

COMMANDING OFFICER
NAVPOLAROCEANCEN
NAVY DEPT.
4301 SUITLAND RD.
WASHINGTON, DC 20390

NAVAL POSTGRADUATE SCHOOL
METEOROLOGY DEPT.
MONTEREY, CA 93943

COMMANDER (2)
NAVAIRSYSCOM
ATTN: LIBRARY (AIR-723D)
WASHINGTON, DC 20361-0001

COMMANDER
NAVAIRSYSCOM (AIR-330)
WASHINGTON, DC 20361-0001

USAFETAC/TS
SCOTT AFB, IL 62225

DIRECTOR (12)
DEFENSE TECH. INFORMATION
CENTER, CAMERON STATION
ALEXANDRIA, VA 22314

LABORATORY FOR ATMOS. SCI.
NASA GODDARD SPACE FLIGHT CEN.
GREENBELT, MD 20771

EUROPEAN CENTRE FOR MEDIUM
RANGE WEATHER FORECASTS
SHINFIELD PARK, READING
BERKSHIRE RG29AX, ENGLAND

END

FILMED

7-85

DTIC